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# Articulated Bus Report

Final Report
July 1982

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16. Abstract

This study examines the performance of articulated buses under actual operating conditions. It documents current applications of these vehicles in revenue service, service characteristics in these settings, the maintenance experience to date, and the costs and benefits of articulated bus utilization in comparison to comparable deployments of conventional coaches.

The study is based on experiences in eleven cities with the articulated bus manufactured by Maschinenfabriken-Augsburg-Nurnberg (MAN) Aktiengesellshaft of West Germany in partnership with AM General (AMG) of the United States. The AMG/MAN vehicles are the only articulated buses in use in the U.S. in sufficient numbers to permit evaluation of their performance and service impacts.

The 60-foot AMG/MAN bus has a capacity approximately 50% greater than that of a 40-foot conventional bus, which makes it possible to substitute articulated buses for conventional buses in some fractional ratio. The major attractiveness of articulated buses is the driver labor cost savings which results from the elimination of in-service buses when articulated buses are substituted in such a fractional ratio. On the other hand, the articulated bus has a capital cost 80 to 100 per cent higher than that of a conventional bus, requires more costly and more frequent maintenance, and takes somewhat longer to complete in-service runs due principally to differences in dwell times at stops.

The analysis conducted suggests that the substitution of articulated buses for conventional coaches may not necessarily be cost-beneficial in many instances. Where articulated buses are substituted in some fractional ratio less that one, longer wait times and in-vehicle times are among the obvious, likely impacts which must be traded off with the cost savings that can often be achieved. Careful analysis is, therefore, required to judge the merits of any local application.

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Articulated Bus, High Occupancy Vehicle, Transit Operator, Conventional Bus, Transit Service, Bus Maintenance Costs, Bus Operating Costs, Bus Capital Costs, Cost-Benefit Analysis

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# PREFACE

This report was prepared jointly by the Urban and Regional Research Division of the Transportation Systems Center (TSC) and Cambridge Systematics, Inc. under the sponsorship of UMTA's Service and Methods Demonstration (SMD) Program. Cambridge Systematics, Inc. performed the field work in this study, and analyzed the performance and service characteristics of articulated buses and transit operator experiences. Stephen Cummings and William Jessiman were the principal authors of Chapters 2, 3, and 4 which summarize the findings of this aspect of the study. Others at Cambridge Systematics who contributed to this work include James Wojno, J. Royce Ginn, and Pam Reid. A special acknowledgement is due to William Byrne, now at Denver's RTD, who prepared a preliminary report which formed the basis for the section on the use of the AMG/MAN bus in the U.S.

The Urban and Regional Research Division of TSC provided technical direction for the study and conducted the cost analysis and benefit-cost tradeoff assessment. Robert Waksman performed the cost analysis and was the principal author of Chapter 5. Richard Albright performed and documented the benefit-cost assessment presented in Chapter 6. Howard Slavin synthesized the findings of the overall study, authored the Executive Summary, and developed the recommendations for further study.

The authors wish to acknowledge the assistance of a number of people who also contributed to this report. We are especially grateful to the people at all of the transit authorities -- drivers, mechanics, and staff -- who gave us some of their time and the information we required to produce this report. The great number of such people prevents us from acknowledging each by name; nevertheless, we would like to thank all those people who assisted.

At the Chicago Transit Authority, Harold Geissenheimer, General Operations Manager, was particularly gracious in sharing his experiences with us. Among the many others at CTA who assisted us were Mr. Mallhi, Harold Hirsch, Robert Vance, Stephen Stark, and Frank Venezia. Byron Yehling was extremely helpful in answering the many questions we had about VMS, CTA's "Vehicle Maintenance System." The CTA provided us with much of the maintenance and cost data used in this evaluation.

At the Port Authority of Allegheny County, Hank Cusack was a cordial and informative host. Philip Castellano, Chuck Martier, and Ralph Burelli all gave us valuable insights into the articulated bus' operation in Pittsburgh. In Phoenix, Ed Colby, the Transit Administrator, was kind enough to allow us to review data about the operations of the Phoenix Transit. T.J. Ross, the Director of Maintenance and Purchasing, guided us around Phoenix Transit's garaging facilities and gave us much of the data we needed.

Many people from Seattle's Metro assisted us, in particular, Gary Galagher, Stuart Bothwell, Barbara Fogle and Tom Freidman. Joel Woodhull of the SCRTD in Los Angeles provided us with sample boarding counts along some routes traversed by articulated buses and was a source of useful counsel concerning articulated bus deployment.

Finally, we wish to express our gratitude to Ron Fisher and Joe Goodman of UMTA's Office of Service and Methods Demonstrations whose patient guidance and helpful insights greatly improved this study.

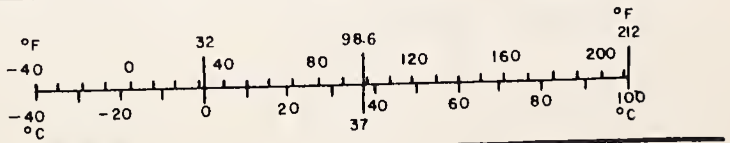
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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# EXECUTIVE SUMMARY

Escalating transit deficits have led the transit industry to search for methods for improving productivity and reducing operating costs. In seeking these objectives, there has been renewed interest in the cost-saving potential of high-capacity articulated buses.

Articulated buses have been used in the U.S. before. Tractor-trailer type buses and trolley buses were built by Flyer and Twin Coach during World War II, and other designs were constructed during the middle and late fifties. Nevertheless, articulated bus utilization did not flourish here as it did in Europe where these vehicles are commonly in use.

Recently, however, U.S. transit properties have begun implementing articulated bus service or are planning to do so in the near future. In order to provide the transit industry with information helpful in making decisions about articulated bus investment and utilization, UMTA's Service and Methods Demonstration (SMD) Program has sponsored this study of the recent articulated bus experience in the U.S. The SMD Program sponsors the demonstration and evaluation of innovative transit techniques and services which rely on existing technology and have the potential to produce near-term improvements in transit service and efficiency.

This study examines the performance of articulated buses under actual operating conditions. It documents current applications of these vehicles in revenue service, service characteristics in these settings, the maintenance experience to date, and the costs and benefits of articulated bus utilization in comparison to comparable deployments of conventional coaches.

The study is based on experiences with the articulated bus manufactured by Maschinenfabriken-Augsburg-Nurnberg (MAN) Aktiengesellshaft of West Germany in partnership with AM General (AMG) of the United States. The AMG/MAN vehicles are the only articulated buses in use in the U.S. in sufficient numbers to permit evaluation of their performance and service impacts. These vehicles, which have 64 - 71 seats and 125 - 150 square feet of standing area, are of considerably higher capacity than conventional coaches such as the General Motors "New Look" bus which has 50 seats and approximately 85 square feet of standing area.

In the course of the study, a review was made of the use of articulated buses in 11 sites based on discussions with individuals involved with the various aspects of articulated bus operations -- managers, drivers, schedule-makers, dispatchers, maintenance staff, etc. Data from Seattle, Pittsburgh, and Chicago were analyzed in detail, and additional data were obtained from other operators to assess the articulated bus experience in quantitative terms.

The eleven U.S. transit operators who have used the AMG/MAN bus in the past two years are listed in Table 1. Information on fleet size (as of November 1979) and on service deployment are also shown. Since that time, some of these operators have ordered additional articulated buses and other operators have placed their initial orders for these buses.

## TABLE 1

### Summary of U.S. Usage of the AMG/MAN Articulated Bus
(as of November 1979)

| City | Operator | No. of Artics | Total Buses in Fleet | Artic Deployment |
|---|---|---|---|---|
| Seattle | Municipality of Metropolitan Seattle (Metro) | 150 | 800 | Overloaded peak routes; suburban express service. |
| San Diego | San Diego Transit Corporation | 44 | 320 | Three most heavily travelled routes (one a 20-mile run from Mexican Border to Downtown San Diego). |
| Washington, DC | Washington Metropolitan Area Transportation Authority (WMATA) | 43 | 1567 | Complete service on single, medium length route through downtown. |
| Oakland | AC Transit | 30 | 628 | Transbay express service; slow, heavy local routes. |
| Los Angeles | Southern California Rapid Transit District (SCRTD) | 30 | 2500 | Mixed service on two major heavily loaded (all day) routes. |
| Minneapolis | Metropolitan Transit Commission (MTC) | 20 | 856 | Peak hour substitution on overloaded local and express routes. |
| Chicago | Chicago Transit Authority (CTA) | 20 | 2400 | Rotating service through all local routes; heavy downtown routes; special events. |
| Pittsburgh | Port Authority of Allegheny County (PAT) | 20 | 751 | Heavily loaded, longer, express routes. |
| Phoenix | Phoenix Transit System | 20 | 130 | Express runs. |
| Atlanta | Metropolitan Atlanta Rapid Transit Authority (MARTA) | 10 | 703 | Overloaded peak routes. |
| San Francisco/ Marin County | Golden Gate Bridge Highway and Transportation District (GGBHTD) | 10 | 227 | Primarily in local service on a long, heavily patronized suburban route. |

The major findings of our research are discussed in the remainder of this summary following the organizational framework employed for the full study report. First, the design of the MAN articulated bus and its operating characteristics are described. Second, the service characteristics which accompany articulated bus deployment are analyzed. Third, the maintenance experience to date is discussed in terms of repair frequency and costs. Next, a comparison of the capital and operating costs of articulated buses and conventional buses is given. Since articulated bus utilization typically has service impacts on travelers as well as cost impacts, a tradeoff analysis was performed to identify situations in which articulated bus utilization is favorable in cost-benefit terms. The results of this analysis and suggestions for further research are the final topics discussed.

## The MAN Articulated Bus and its Operating Characteristics

The MAN bus depicted in Figure 1 is a three-axle vehicle powered by a uniquely designed "pancake" engine, mounted under the floor just over the middle axle which it drives. The bus is manufactured in two lengths -- 55 feet and 60 feet in length. The 60-foot bus comes in either a 2 or 3 door model while the 55-foot bus only comes in a 2 door version.

Figure 1 also shows a typical seating layout of a 55-foot articulated bus and that of a conventional 40-foot GM bus for comparison. The obvious differences between the articulated bus and conventional bus are in length, number of axles, and the presence of a turntable (the "bending" portion) in the articulated bus. Other features of the articulated bus which distinguish it from conventional buses are wider doors, an extra step, and shorter steprisers. These features offer the potential for faster or easier boarding and deboarding.

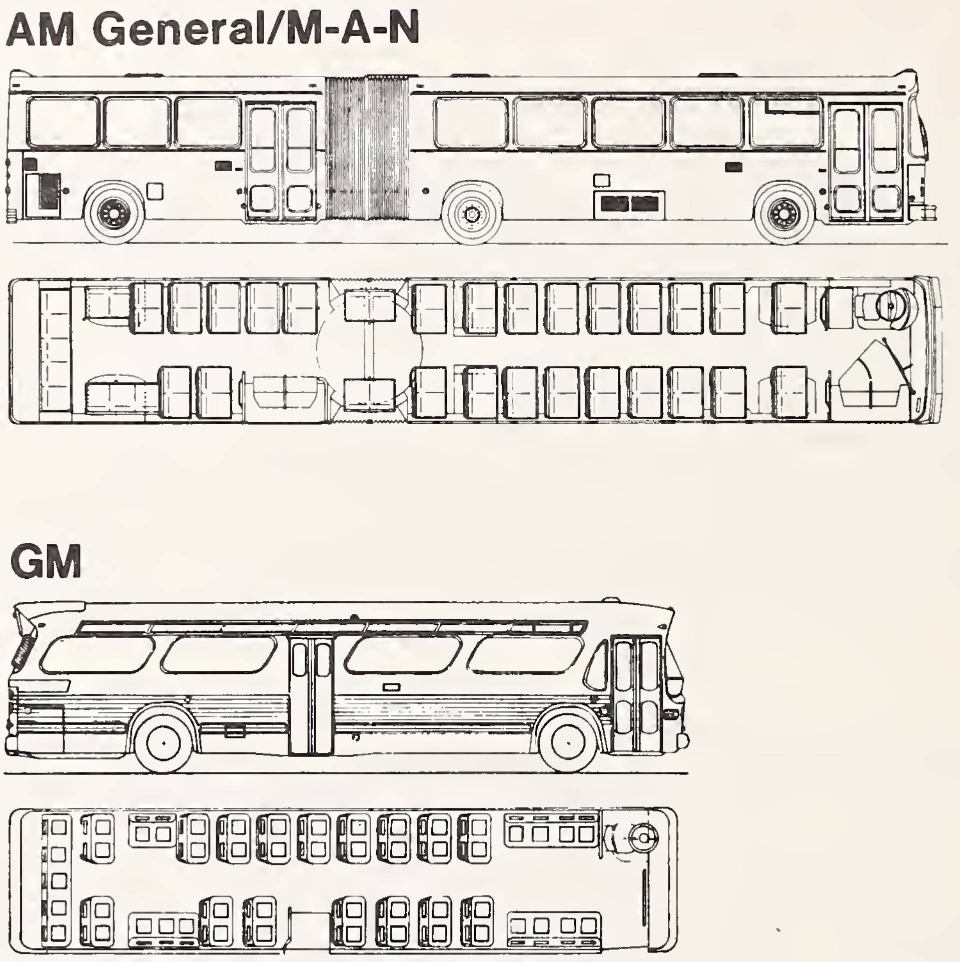
The articulated bus is wider and heavier than a conventional bus, but it has a lower horsepower engine. Many drivers feel that the articulated bus is underpowered, particularly going up hills or accelerating onto a freeway.

With its extra length and unique design, the articulated bus handles differently than a conventional bus and has several features to which drivers must become accustomed. The most important of these features is the swing-out of the rear of the bus during turns. Moving in reverse also presents a learning problem for the articulated bus driver. Improperly done, reversing the bus will cause major turntable damage. Some drivers preferred one type of bus to the other, seemingly as a matter of personal taste.

It is perhaps premature to draw any firm conclusions regarding the articulated bus' accident and safety record because of data and experience limitations to date. However, Minneapolis, Phoenix and Pittsburgh data reveal double to triple the accident rate per vehicle mile for the articulated bus than that for a conventional bus. A high percentage of these accidents appears to result from the tendency of the rear end of the articulated bus to swing out during turns, so it is possible that the articulated bus accident rate will decrease as drivers become more familiar with the bus.

## Service Characteristics

The service characteristics of the articulated bus in revenue service are critical determinants of its attractiveness to the transit industry and the



SOURCE: Chicago Transit Authority, Operations Planning Dept.

FIGURE 1

<u>Layouts of the AMG/MAN Articulated Bus and the GM "New Look" Conventional Bus</u>

travelling public. For this reason, considerable effort was devoted in our study to assessing articulated bus service characteristics relevant to operators and passengers.

Examination of articulated bus deployment in the eleven cities failed to reveal any systematic pattern of application of these vehicles in revenue service. Rather, the articulated bus has been utilized to provide a wide variety of transit services. Typically, transit operators had not yet made any major adaptations in schedules or routes to take full advantage of the higher capacity of the articulated bus. We believe, however, that there is general agreement that special planning and scheduling efforts will be needed to realize the economic and service potential of articulated buses.

A crucial characteristic of the articulated bus is its passenger carrying capacity. It is estimated that the capacity of the 60-foot AMG/MAN bus is 106-124 passengers of whom 35-53 are standees, which is approximately 50% greater than the capacity of a 40-foot conventional bus of 70-80 passengers including 20-30 standees. The ranges in the numbers of standees arise from varying the amount of standing space per standee, which is assumed to be the same for both types of buses.

Capacity estimates, of course, refer to a number of passengers that a vehicle could carry under circumstances of excess demand and will vary with many physical and behavioral factors. Actual loads carried, however, may fall considerably short of capacity. Indeed, the limited data available to us may suggest that in many cases passenger loads found on articulated buses are similar to those on conventional buses. This again illustrates the need for special management attention when deploying articulated buses.

Despite the lower power-to-weight ratio of the articulated bus, operating data collected in two cities indicated that articulated buses had essentially the same running times between stops. Thus, in current applications, it appears that articulated buses can achieve the same operating speeds as a conventional bus except on grades. Of course, operators have avoided utilizing articulated buses in locations where their performance characteristics would lead to operating or service problems. Apart from these situations, our analysis of run time data suggests that other factors such as traffic conditions and signal settings largely determine travel speeds for all types of buses.

Total in-service run times for articulated buses are estimated to be from 1 to 7 minutes greater than for conventional buses due principally to differences in dwell times at stops. Differences in dwell time are attributable, in part, to slower door openings and closings for the articulated bus which increases dwell times by one to two seconds per stop irrespective of passenger loads. The higher passenger loads that will typically be associated with efficient articulated bus deployment will also increase dwell times because of the increased time needed to process the greater number of boardings and deboardings.

These longer in-service run times lead to travel time increases for passengers even if the same frequency of service is maintained when articulated buses are used in place of conventional coaches. The actual magnitude of the differences in in-service run times between articulated bus service and conventional bus service will obviously depend upon route characteristics and passenger loads. Generally, however, one would expect that these differences will be smaller for express routes, on which the total number of stops, boardings, and deboardings are relatively low, and greater for local routes, on which the number of stops, boardings, and deboardings tend to be higher.

Because of their differing service characteristics, the use of articulated buses in mixed service with conventional buses on the same high frequency routes may exacerbate bus bunching problems. These problems become worse because of the different, longer dwell times of articulated buses. It is possible that changes in schedules and operating strategies could reduce the frequency and severity of bunching but this is a matter for future investigation.

In theory, the wider and more numerous doors on the 60-foot articulated bus should reduce dwell time per passenger boarding and deboarding. Statistical analysis suggested that a small improvement on the order of 7 to 15 percent does occur, but that the effect is smaller than would be expected and typically dominated by the slow opening and closing of doors. Relatively infrequent use is made of the articulated buses' double-width doors to process two streams of passengers simultaneously.

It should be noted that the conclusions above are not independent of existing operating practices and that this fact could result in different conclusions being reached concerning articulated bus dwell times in other situations. As one example, it should be noted that fare payment and collection methods can have a large impact on dwell times. In our statistical analysis, however, it was not possible to quantify this effect because of insufficient data and because of relatively little variation in the manner of fare payment. There is reason to believe, however, that other methods of fare payment such as self-service fare collection would lead to considerably reduced boarding and alighting times for articulated buses.

## The Articulated Bus Maintenance Experience

The findings regarding the maintenance experience with articulated buses are based on observations made during informal discussions with foremen, mechanics, and repairmen as well as from data collected and reported to the study team by transit operators themselves. The analysis of the maintenance experience of the articulated bus is limited, however, by several factors. First, since the bus has only recently been introduced to this country, some of the maintenance activity can be attributed to the "breaking-in" which accompanies any new vehicle. Some of these problems are chargeable directly to the bus' warranty and thus do not impact the operator's maintenance costs. Ideally, comparisons of maintenance rates between different vehicles should take warranty repairs into consideration. Unfortunately, warranty claims are included in the maintenance records and could not be separated from non-warranty service in the analysis. Second, evaluating the working life of components was also impossible in many instances because of their relatively long life and the vehicle's brief operational history; most components simply have not yet been in use for a sufficient length of time to permit an evaluation of component life.

A third limitation of the analysis is the confounding effect of the use of service personnel provided without additional charge by the manufacturer.

In every site visited, MAN had a full-time field representative resident for one year to help in the repair of articulated buses; AMG had local field representatives visit on a part-time basis. The field representatives were experienced technicians, familiar with all aspects of maintenance for the articulated bus, and were typically thought to be invaluable by the operators. The representatives' services were not included in the accounting of mechanics' time at each property. Unlike the inclusion of warranty repair data, which inflates estimates of maintenance requirements, this factor causes maintenance efforts to be understated. The net effect of these influences, however, could not be determined and the findings presented below do not take into account either of these factors.

The principal repair problems of the MAN articulated bus cited by operators were related to its air conditioning system, turntable, and engine belts. The air conditioning system is American made and installed by AMG in the United States; this particular unit has had many problems. Each of the transit authorities contacted has stated that the air conditioning unit breaks down too frequently. When asked, "what problems are you having with the articulated bus?", the air conditioning unit was almost invariably the first item mentioned. The manufacturer is studying revisions to the design of the air conditioning system and is expected to offer a newer version in future bids.

The articulated bus, as with any vehicle with a trailer, can be "jack-knifed" if improperly driven. The manufacturers were aware of this potential problem and placed two sets of switches on the turntable to help prevent its occurrence. The first warns the driver with a buzzer and flashing light that the angle is becoming too sharp. The second locks the brakes if the angle grows any sharper--hopefully before damage can occur to the turntable. Experience with these devices has shown that they have not always been effective. Although there were insufficient data to obtain a good estimate of the incidence of turntable damage, the problem has been severe enough to lead several operators to make some minor equipment modifications.

All operators reported difficulty in maintaining the proper adjustments for the belt and pulley systems used in the articulated bus' pancake engine and its air conditioner engine. It was apparent that some of the difficulty resulted from unfamiliarity with belt systems of this type; engines of American-made buses employ belted components to a lesser extent. Nevertheless, there were problems with the belts themselves which the manufacturer is currently trying to solve by repositioning mounting brackets and by utilizing belts made of different material. In fairness, it should also be noted that operators have reported similar difficulties with the belts used in the air conditioning system of the Grumman 870 Advanced Design Bus.

Parts availability and cost has been a concern for every operator. Most operators report that the magnitude of the problem has been reduced since the early period of the articulated bus utilization for two reasons. First, operators are learning what parts are likely to fail and how many of each part is required in inventory to be able to fulfill requirements when faced with long lead times for orders. Second, parts which earlier were available only from German manufacturers have begun to become available from manufacturers in this country. This has reduced both price and lead times for orders.

When discussing the cost of parts, it is important to differentiate between the American-made components and those produced by German manufacturers. The American-made parts, which include those for the air conditioning, lighting, fixtures, and windows, tend to be comparably priced to similar components on conventional buses. The German-made parts, which constitute most of the running gear of the bus, are imported and furnished to the various transit authorities through AMG. These parts are about twice as expensive as comparable parts for American-made buses. There are, however, encouraging signs that purchasing from other domestic and foreign sources can reduce these costs.

Besides a longer lead time for parts, one other factor contributes to the need to maintain a larger inventory of parts for the articulated bus. Many of the parts that are inventoried for the various models of conventional bus can be shared among the different buses, especially those that have the same engine type. Articulated buses currently cannot share parts with other buses.

The only detailed maintenance data for comparison of articulated and conventional buses were provided by Chicago for its fleet of 20 articulated buses and for 20 of its 1976 vintage GM "New Look" buses. Chicago's records show 5.7 repairs per 1,000 miles for the articulated bus versus 2.3 repairs per 1,000 miles for its 1976 GM conventional bus. However, these numbers and all comparisons using the Chicago data should be tempered by the fact that the 1976 GM buses have much better performance than the "average" CTA bus, i.e., their maintenance costs per mile are about 45% lower.

In Chicago, preventive maintenance visits to the shop are 129 percent more frequent for the articulated bus than for the 1976 GM conventional bus; they account for about 40 percent of the shop visits for both bus types. Air conditioning repairs accounted for almost a quarter of all articulated bus repairs in Chicago exclusive of preventive maintenance. If preventive maintenance shop visits and air conditioning repairs are removed from the Chicago data comparison, the articulated bus still has an incidence of 86 percent more repairs per 1,000 miles than does the 1976 GM conventional bus.

It could be hypothesized that the higher repair rate for the articulated bus is in part attributable to its newness and that the frequency of repair should decline as the transit industry gains more experience with these buses. However, repair records in Chicago showed little improvement over a period of a year and a half.

Moreover, Chicago's records indicate an overall average of 2.9 mechanic labor hours per articulated bus repair versus 2.2 hours for the 1976 GM conventional bus. The articulated bus has required more time for comparable repairs in 18 of 19 repair categories. There has also been no noticeable decrease over time in labor resources per vehicle mile for articulated bus maintenance.

The data are somewhat less conclusive on whether the articulated bus requires more road calls than the conventional bus. Chicago had 52 percent more road calls for the articulated bus (4.4 road calls per 10,000 miles versus 2.9 for its 1976 GM conventional bus); Phoenix had 127 percent more road calls for the articulated bus (3.4 versus 1.5 per 10,000 miles for its 1979 GM RTS-II bus); Seattle, on the other hand, experienced 41 percent fewer road calls per 10,000 miles (2.7 versus 4.6 for its conventional bus, a 1976

AMG). Seattle, it should be noted, is the only one of the three properties that does not have air conditioning in its articulated buses.

## Capital and Operating Costs

The greater passenger-carrying capacity of articulated buses makes it possible to use them to transport travellers with fewer vehicles than would be required if conventional buses were used. Whether in replacing existing vehicles or in adding vehicles to a fleet, the substitution of articulated buses for conventional buses should thus yield direct savings in driver labor costs. If these cost savings exceed the sum of the higher capital and non-driver operating costs associated with articulated bus utilization, then overall cost savings accrue.

The cost analysis conducted in our study compares the costs of articulated bus purchase and operations with those for conventional coaches. As is reflected in the discussion above, the choice between these vehicles is open to operators regardless of whether they wish to increase or decrease the size of their fleets or change the volume of service provided to consumers.

In our analysis, costs are estimated for the 60-foot articulated bus. Costs of the 55-foot bus are very similar, although its capacity is less. Consequently, it is our view that the longer articulated bus is to be preferred in most instances. For this reason, our analysis assumes that 60-foot buses are utilized in all articulated bus scenarios examined.

The relative purchase prices of articulated and conventional buses will vary with order size and accessories desired, and many factors will determine the relative prices of the two buses in the future. Based on 1980 delivery, an articulated bus with air conditioning has a price in the range of $235,000-$260,000. Two recently available conventional buses, the GM RTS-II and the Grumman 870, both air conditioned, cost approximately $130,000 in 1980.

Non-driver operating costs (i.e., vehicle maintenance, fuel, insurance) for conventional and articulated buses can be compared in terms of average annual costs given the same number of miles of operation for both types of buses. APTA 1980 operating statistics for a sample of large U.S. properties provide the following average annual non-driver operating cost estimates for a conventional bus:

Maintenance (including labor) = $14,000
Fuel = 10,000
Insurance = 4,000
Total = $28,000

Since most transit properties are self-insured, the insurance cost estimate above is based upon the costs of liability claims.

In our study, operating cost data for the articulated bus are derived by comparison with conventional buses. The detailed data from Chicago supplemented by limited data from other sites indicate that per mile maintenance costs for articulated buses are one and one-half to two times those for conventional buses. Data from five cities suggest that articulated buses average about 3.2 miles per gallon versus 3.6 miles per gallon for conventional buses. Thus, per mile fuel costs are estimated to be 10% higher for articulated buses. However, these fuel cost estimates may be optimistic since the articulated buses at the five sites tend to be operated on routes such as express routes on which fuel efficiencies are likely to be higher. The two to three times higher accident rate for the articulated bus is expected to result in a per mile liability claim cost for the articulated bus at least twice that for the conventional bus.

Thus, annual non-driver operating costs per articulated bus for buses operated the same number of miles as an average conventional bus are estimated to be as follows:

Maintenance = $21,000 to $28,000
Fuel = 11,000
Insurance = 8,000
Total = $40,000 to $47,000

Actual annual non-driver operating costs incurred will be directly proportional to the mileage articulated buses accumulate relative to that for an average conventional bus.

Articulated buses normally would be operated considerably fewer miles per year on average than conventional buses. Since efficient articulated bus utilization typically will occur at times of high passenger loading (generally in the peak period only), and since conventional buses have a lower per mile operating cost than articulated buses, operating cost savings are gained by limiting articulated bus operation to periods of high passenger loading. The much lower yearly mileage that articulated buses consequently experience when deployed in this manner also results in longer articulated bus life and shorter conventional bus life, since the average annual utilization of the remaining conventional buses in the fleet must rise. Depending upon the manner in which they are utilized, it is estimated that articulated buses will accumulate mileage at between 40 percent and 75 percent of the rate of conventional buses in an all-conventional bus fleet.

Annual driver labor cost savings are directly related to the elimination of in-service conventional buses resulting from the substitution of articulated buses in some fractional ratio. For each in-service conventional bus eliminated in the peak period only, it is estimated that approximately $35,100 in driver labor costs will be saved per year based on a $10.00 per hour base driver wage rate. This estimate is based on the assumption that the elimination of each in-service bus results in the saving of one split shift driver assignment (composed of a morning and afternoon piece of work). For each in-service conventional bus eliminated during the entire day (weekdays only), it is estimated that approximately $47,300 in driver labor costs will be saved annually based on the $10.00 per hour base wage rate. This estimate is based on the assumption that the elimination of each in-service bus results in the saving of a straight 8 hour assignment and one half of a split shift assignment. Actual labor savings at a given property will depend on the property's base wage rate, cost of fringe benefits, work rules, and other factors.

Total driver labor cost savings resulting from the implementation of an articulated bus replacement strategy are calculated by determining the number of conventional buses that will be eliminated and multiplying that number by the annual savings per bus eliminated. Of course, the major determinant of the number of in-service buses that will be eliminated is the operator's decision as to the appropriate articulated bus substitution rate. However, in determining the number of in-service conventional buses that will be eliminated, other factors must also be taken into account.

One factor is that in-service travel times are longer with articulated buses so that somewhat more vehicles are needed to provide a given volume of service (since vehicles cannot be turned around as quickly to make subsequent trips). This reduces the number of in-service conventional buses that are eliminated by articulated bus implementation and, hence, cuts into the potential labor savings. The need for more vehicles also results in higher capital expenditures. It is estimated that to compensate for the articulated buses' slower in-service travel times, the number of articulated buses and drivers must be increased as much as 4.5% on local routes and 1.5% on express routes.

Another factor considered in assessing the costs of articulated bus utilization is a higher incidence of road calls and non-scheduled maintenance with articulated buses. Detailed bus maintenance and road call data collected in Chicago, as well as less complete data from Phoenix and Seattle, suggest that the incidence of in-service vehicle breakdowns and non-scheduled maintenance is at least 50% higher for articulated buses than it is for conventional buses. It is estimated that 4% more articulated buses are needed to insure that the higher incidence of road calls and repairs does not lead to a higher incidence of missed peak period trips on routes on which articulated buses are deployed.

A present value analysis of costs has been used to calculate the total costs (capital plus operating) resulting from articulated bus deployment. Separate estimates of costs were calculated from the societal perspective and from the transit operator's perspective. The societal perspective considers all capital and operating costs since society ultimately bears these costs. Costs from the transit operator's perspective are reduced by the amount of Federal capital and operating subsidies. Our analysis consequently takes into account the fact that currently transit operators pay 20% of capital costs and an average of 87% of operating costs. The analysis, however, does not take into account any state or local subsidies.

Because of the range of values possible for each of the components of cost, there is considerable uncertainty as to the total costs of articulated bus deployments. To help cope with this uncertainty, high and low estimates of cost savings have been calculated. The high estimate gives the more favorable view of the articulated bus utilization as it assumes a low-end non-driver operating cost of $40,000 per bus and a high-end labor wage rate of $11.00 per hour. The low estimate gives a less favorable view of articulated bus utilization as it assumes non-driver operating costs of $47,000 per bus and a low-end wage rate of $9.00 per hour.

A summary of numerical estimates of cost savings resulting from the substitution of articulated buses for conventional buses is provided in Table 2. Estimates are included for three deployment scenarios -- peak-period express service, peak period local service, and all day local service.

As reflected in Table 2, the results of the cost analysis lead to the following observations on cost savings at different articulated bus substitution rates:

(1) One-for-two substitution of articulated buses for conventional coaches yields substantial cost savings due to both driver labor cost savings and other operating cost savings, with capital expenditures little different from those incurred in the purchase of conventional buses (since twice as many conventional buses would be purchased).

(2) Cost savings will generally accrue at a two-for-three substitution rate. These cost savings result from driver labor cost savings which more than offset the higher articulated bus capital costs.

(3) At a three-for-four substitution rate, articulated bus cost savings are slight and possibly non-existent in all three deployment scenarios.

(4) A one-for-one substitution results in cost increases due to higher capital and non-driver-related operating costs of articulated buses without any savings in driver operating costs.

Another observation to be made from Table 2 is that it is clear that estimates of cost savings differ from the societal and operator perspectives. In some instances, deployment scenarios which are cost-saving to operators could increase costs to society. This is to be expected as a nominal consequence of the availability of Federal subsidies.

## Cost-Benefit Tradeoffs

The purchase and deployment of articulated buses in place of or in addition to conventional coaches necessarily impacts the characteristics of service provided to existing and potential transit riders. Even if measures are taken to calculate cost savings based on comparable deployments of articulated and conventional buses, inevitable differences in level-of-service benefits will remain which must be taken into account in assessing the desirability of articulated bus utilization.

In fact, extreme caution must be exercised by transit operators in judging the benefits to be obtained by the substitution of articulated buses for conventional buses at some fractional ratio less than one. In these instances, longer wait times and in-vehicle travel times are among the obvious, likely impacts which must be traded-off with the cost-savings that can be achieved. There may also be lost schedule opportunities and changes in seat availability, schedule reliability, or the probability of being bypassed which result from articulated bus deployment. Increased seat availability can lead to increases in ridership and revenues while some of the other service impacts can result in a decline in ridership and revenue.

Clearly, an assessment of the potential service implications of articulated buses is just as important as an assessment of the potential cost implications. To arrive at a rational decision regarding the adviseability of substituting articulated buses for conventional buses, a means for weighing the cost impacts against the service and revenue impacts must be employed.

TABLE 2

Summary of the Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Different Types of Service
(cost savings in $1000's/articulated bus deployed)

| | | peak period express service | | peak period local service | | all day local service | |
|---|---|---|---|---|---|---|---|
| substitution rate | estimate | societal perspective | operator perspective | societal perspective | operator perspective | societal perspective | operator perspective |
| 1-for-2 | high | 37.8 | 32.9 | 33.2 | 28.9 | 50.3 | 41.3 |
| | low | 27.1 | 25.1 | 21.1 | 20.0 | 28.2 | 31.1 |
| 2-for-3 | high | 11.2 | 13.2 | 6.8 | 9.5 | 15.3 | 11.7 |
| | low | 3.4 | 8.0 | ( 2.1) | 3.4 | 4.8 | 5.9 |
| 3-for-4 | high | 2.4 | 6.7 | ( 0.5) | 4.1 | 3.7 | 6.8 |
| | low | ( 4.4) | 2.3 | ( 8.3) | ( 1.0) | ( 5.7) | 0.4 |
| 1-for-1 | high | (14.8) | ( 6.0) | (15.3) | ( 7.3) | (18.2) | ( 9.5) |
| | low | (19.7) | ( 8.8) | (20.9) | (10.7) | (25.7) | (14.3) |

NOTE: Figures in parentheses, i.e., negative cost savings, represent cost increases.

This study utilizes one mechanism for weighing cost savings against service losses. In our simple cost/benefit analysis, changes in user level-of-service benefits and operator revenues are traded off against the annual capital and operating cost savings realized by the transit operator.

Several variations of the simple evaluation technique are used in this report to study the cost-effectiveness of articulated buses in a variety of scenarios. Resource constraints prevented the use of computer simulation to predict the service impacts in these cases, so a measure of professional judgment was required. Similarly, changes in ridership and in user benefits were calculated from a judgmentally estimated demand model. The use of hypothetical scenarios, simple evaluation techniques, and subjective judgment necessarily renders the conclusions resulting from this analysis tentative. Still, the results are logically consistent and persuasive.

Scenarios based on those used for estimating cost savings were analyzed. The numerical results from the analysis are given in Tables 3 and 4 from the perspectives of society and transit operators, respectively.

The hypothetical examples studied here strongly support the belief that articulated buses are very cost-effective when used to replace conventional buses operating as "double-headers". Furthermore, it is shown that articulated buses may be cost-effective in express service from both the operator and societal perspective when used to replace conventional buses at approximately a 2-for-3 ratio. However, in no local service situation analyzed in our work do articulated buses appear to be cost-effective. This conclusion appears to hold over a broad range of service parameters, substitution rates and cost assumptions. Based on this analysis, the decision to employ articulated buses on local routes should be made cautiously and only after a careful analysis of conventional bus deployment alternatives.

## Concluding Remarks and Recommendations for Further Work

It is obviously impossible in a general study of this nature to draw conclusions on the desirability of articulated bus utilization on a particular route or in a specific local setting. Therefore, we would not presume to judge the merits of any local application. Nevertheless, the cautious stance that emerges from our work is apparently at some variance with the enthusiasm with which the articulated bus is viewed by at least a subset of transit operators. This different judgment is difficult to explain, but we might speculate that it is largely the result of our use of more extensive data and a more rigorous and comprehensive evaluation methodology than operators currently employ.

In any case, we share the view of transit operators that there may be significant changes over the next few years in the costs of articulated bus purchase and utilization. There may, of course, also be significant changes in these costs for conventional bus alternatives. Clearly, the comparative costs of articulated bus service bear careful monitoring in the near term by those involved in making bus purchase decisions.

At the same time, there is a strong case for aggressive efforts to make the best use of the existing and growing number of articulated buses in U.S. transit vehicle fleets. The need for special analytical and management efforts to realize the productivity enhancement potential of the articulated

TABLE 3

## Summary of Societal Tradeoff Analysis Results

| OPTION | (1) ANNUAL GAIN IN USER BENEFITS[1] ($x1000) | (2) ANNUAL COST SAVINGS[2] ($x1000) |  | (3)=(1)+(2) NET ANNUAL SOCIETAL GAIN[3] ($x1000) |  | (4) BUSES PURCHASED[4] | (4)=(3)/(4) NET ANNUAL SOCIETAL GAIN PER BUS PURCHASED[5] ($x1000) |  |
|---|---|---|---|---|---|---|---|---|
|  |  | low | high | low | high |  | low | high |
| Local Bus Options: |  |  |  |  |  |  |  |  |
| 1. 1:1 | 66.9 | (363.9) | (257.7) | (297.0) | (190.8) | 14.16 | (21.0) | (13.5) |
| 2. 3:4 Peak, Mixed Fleet | (147.7) | ( 58.8) | ( 3.5) | (206.5) | (151.2) | 7.08 | (29.2) | (21.4) |
| 3. 2:3 | (453.9) | 45.3 | 144.4 | (408.6) | (309.5) | 9.44 | (43.3) | (32.8) |
| Express Bus Options: |  |  |  |  |  |  |  |  |
| 1. 1:1 | 69.0 | (139.5) | (104.8) | ( 70.5) | ( 35.8) | 7.08 | (10.0) | ( 5.1) |
| 2. 2:3 | ( 43.5) | 16.0 | 52.9 | ( 27.5) | 9.4 | 4.72 | ( 5.8) | ( 2.0) |
| 3. 1:2 | (350.6) | 95.9 | 133.8 | (254.7) | (216.8) | 3.54 | (71.9) | (61.2) |
| Double-Header Options: |  |  |  |  |  |  |  |  |
| 1. 1:2 | ( 4.0) | 32.0 | 44.6 | 28.0 | 40.6 | 1.18 | 23.7 | 34.4 |

NOTES:

1. Parentheses indicate a loss of benefits.
2. Parentheses indicate a cost increase.
3. Parentheses indicate a net societal loss.
4. Includes buses out of service due to maintenance requirements and the need for spares.
5. The median net annual societal gain is used.

TABLE 4

## Summary of Operator Cost/User Benefit Tradeoff Analysis Results

| OPTION | (1) ANNUAL GAIN IN USER BENEFITS[1] ($x1000) | (2) ANNUAL COST SAVINGS[2] ($x1000) | | (3) = (1)+(2) NET ANNUAL GAIN [3] ($x1000) | | (4) BUSES PURCHASED[4] | (5) = (3)/(4) NET ANNUAL GAIN PER BUS PURCHASED[5] ($x1000) | |
|---|---|---|---|---|---|---|---|---|
| | | low | high | low | high | | low | high |
| Local Bus Options: | | | | | | | | |
| 1. 1:1 | 66.9 | (202.5) | (134.5) | (135.6) | ( 67.6) | 14.16 | ( 9.6) | ( 4.8) |
| 2. 3:4 Peak, Mixed Fleet | (147.7) | ( 7.1) | 29.0 | (154.8) | (118.7) | 7.08 | (21.9) | (16.8) |
| 3. 2:3 | (453.9) | 55.7 | 110.4 | (398.2) | (343.5) | 9.44 | (42.2) | (36.4) |
| Express Bus Options: | | | | | | | | |
| 1. 1:1 | 69.0 | ( 62.3) | ( 42.5) | 6.7 | 26.5 | 7.08 | .9 | 3.7 |
| 2. 2:3 | ( 43.5) | 37.8 | 62.3 | ( 5.7) | 18.8 | 4.72 | ( 1.2) | 4.0 |
| 3. 1:2 | (350.6) | 88.9 | 116.5 | (261.7) | (234.5) | 3.54 | (73.9) | (66.2) |
| Double-Header Options: | | | | | | | | |
| 1. 1:2 | ( 4.0) | 29.6 | 38.8 | 25.6 | 34.8 | 1.18 | 21.7 | 29.5 |

NOTES:

1. Parentheses indicate a loss of benefits.
2. Parentheses indicate a cost increase.
3. Parentheses indicate a net operator loss.
4. Includes buses out of service due to maintenance requirements and the need for spares.
5. The median net annual operator gain is used.

bus can be filled in a number of ways. First, there is a need for a planning methodology which can be used by operators to identify appropriate settings for articulated bus use and to optimize deployments for specific routes. The cost-benefit approach utilized in our study can, with further development and empirical validation, form the basis for a major part of this planning methodology.

Second, several demonstration projects are recommended to experiment with alternative means of achieving productivity improvements with articulated buses. The projects would be conducted in cooperation with transit authorities who are already utilizing articulated buses. In these efforts, experiments would be conducted with route structures, schedules, and dispatching strategies to ascertain cost-effective efficiency-enhancing techniques for articulated bus utilization.

One project, which includes a precursor research activity, should focus on effective strategies for mixed use of articulated buses and conventional buses on the same route. One or more demonstration projects could focus on specific topics other than service deployment such as fare collection, maintenance, and driver training. These projects would be carefully documented and evaluated and the results disseminated to the transit community.

A third recommended initiative is a follow-up study to update the data, analyses, and conclusions provided in this report. As mentioned previously, the operating experience and the cost of articulated bus utilization may change considerably over the next few years with potentially major implications for investment and deployment decisions.

Perhaps, the greatest uncertainty in assessing the desirability of articulated bus utilization concerns the preferences of transit travellers which ultimately are major determinants of revenues and user benefits. These preferences must be taken into account for efficient service design for all vehicle types. Despite its importance, insufficient research has been done to reach conclusions on the value travellers place on attributes of service such as the availability of a seat, the components of travel time, the possibility of being passed-by by a full bus, etc., to identify the best uses of articulated buses. Consequently, we suggest that a major effort be mounted to estimate the consumer preference data needed for transit service design.

Our final recommendation is that UMTA consider the development and implementation of a modest program of technical assistance to operators to share information and understanding on articulated bus investment and deployment decisions and sound operating practices. If undertaken, this activity should be coordinated with the other activities that are recommended.

# 1. INTRODUCTION

The growing need to improve productivity and decrease costs has led transit operators in the US to reexamine deployment of the high-capacity articulated bus. The currrent articulated bus implementations are hardly the first attempts to utilize these vehicles; tractor-trailer type buses and trolley buses were built by Flyer and Twin Coach during World War II and other designs were constructed during the middle and late fifties. However, although the use of these vehicles flourished in Europe, articulated buses never really caught on in this country. Now, though, the articulated bus is being given serious consideration by U.S. transit properties. In the past few years, a number of properties have acquired articulated buses and have deployed them in various ways.

This report presents the findings of a study of the recent use of and the potential for the articulated bus in the United States. The study is based on the utilization of the articulated bus manufactured by MAN AG (Maschinenfabrik Augsburg-Nurnberg Aktiengesellshaft) of West Germany in partnership with AM General as used in a variety of cities across the U.S. This evaluation of the articulated bus was conducted under the sponsorship of the Service and Methods Demonstration (SMD) Program of the Urban Mass Transportation Administration (UMTA). The SMD Program sponsors the demonstration and evaluation of innovative transit techniques and services that rely on existing technology and have the potential to produce near-term improvements in transit service and efficiency.

The evaluation was specifically limited to the AMG/MAN bus. Although other manufacturers produce articulated buses,[1] at the time of this study, the AMG/MAN bus was the only articulated bus used widely in this country.

## 1.1 Study Objectives and Research Questions

The primary objective of the study was to develop information to assist transit operators in assessing the potential deployments of articulated buses. As such, the study attempted to assess articulated bus deployments in terms of operational, service, and maintenance characteristics, and impacts on their costs and passenger level of service. The study is based upon an analysis of data collected at a number of U.S. transit properties operating articulated buses, but also makes use of more general data on travel behavior, transit operations, and costs, as well as basic statistical and economic methodologies and relationships.

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[1] Among them are Ikarus of Hungary, Volvo of Sweden, and Pegaso of Spain. GM of Canada and Daimler-Benz of Germany are experimenting with an articulated bus design that features an engine in the rear. No American bus manufacturer currently makes an articulated bus, but General Motors plans to have one available in 1983 or 1984.

The study was designed to evaluate the issues that would be of interest to a transit authority considering the addition of articulated buses to their fleet. These issues can be grouped into three broad categories, namely:

- operational and service characteristics: in comparison to the conventional bus, how does the articulated bus operate in different settings?
- maintenance experience: how difficult has the articulated bus been to repair; how frequently are repairs needed; and how different is the articulated bus from the conventional coach in terms of maintenance?
- economic analysis: what are the costs and benefits of articulated bus utilization; under what general circumstances is an investment in articulated buses desirable?

In evaluating the articulated bus' operational and service characteristics, the following questions were explicitly addressed:

- How maneuverable are articulated buses in traffic? Do they have special problems in turning, pulling into and away from stops, or in backing up? Are accident rates higher than those for other buses?
- What are the relative passenger-carrying capabilities of articulated and conventional buses?
- How does the dwell time of the articulated bus compare to that of a conventional coach? What is the net impact of the articulated bus' wider doors and slower door opening speeds? How do higher passenger loads on the articulated bus affect its dwell time?
- Do articulated and conventional buses operate at comparable between-stop speeds along a route?
- How do the dwell time and between-stop running time characteristics of the articulated bus affect its overall travel time?
- Under what kinds of articulated bus deployments are any differences between articulated and conventional bus travel times most significant?

The investigation of the articulated bus' maintenance experience attempted to answer the questions below:

- What kinds of repairs are the most frequently made to articulated buses? How do these repair frequencies differ from those of conventional buses?
- What is the reliability of an articulated bus -- measured in terms of in-service availability -- and how does it compare to that of a conventional bus?

- Are road calls more frequent for articulated buses than for conventional buses?

- How does the cost of spare parts compare by type of bus?

- What problems have there been with articulated bus parts availability and supply?

- How are transit properties conducting the maintenance on the articulated buses? Is much training required?

In the <u>economic analysis</u> of the articulated bus, the key questions examined were:

- What are the capital and operating costs associated with articulated buses? How do these costs compare with those of conventional buses?

- Under what substitution ratios of articulated buses for conventional coaches, e.g., 1-for-2, 2-for-3, etc, and in which deployment scenarios can the use of articulated buses produce cost savings?

- When substituting articulated buses for conventional buses, what are the impacts on passenger level of service? What tradeoffs are there between these level of service impacts and the cost impacts of articulated bus implementation?

- Given these tradeoffs, under what substitution ratios and deployment scenarios should articulated buses be considered for use?

## 1.2 Evaluation Approach

An examination of articulated buses conducted in three cities -- Seattle, Pittsburgh, and Chicago -- forms the basis for many of the observations made and analyses performed in this study. The investigations of the operational, service, and maintenance characteristics of the articulated bus draw heavily on data collected at the three sites. Data from these sites also provide important input to the economic analysis carried out. The three cities were selected to provide a cross-section of properties from across the country. In each of these cities, interviews with operators, mechanics, and transit managers were conducted. Also maintenance data were collected and detailed on-board riding checks were conducted. In addition, data from these cities were augmented with selected data from Phoenix, Los Angeles, San Diego, and Minneapolis, four other cities whose transit operators are experimenting with articulated buses.

At the three primary sites, observations of bus performance were collected during an extensive effort over a four-day period, using personnel hired specifically for this task in each of the three cities. The performance data collected during these field trips included:

- persons boarding (by each door separately)
- persons alighting (by each door separately)

- door-open times (dwell time)
- travel times between stops
- stop location

Statistical analyses of the data, including simple regressions, were used to study and compare between-stop running times and dwell times on articulated and conventional buses.

Maintenance data were gathered during interviews with management personnel and with mechanics. A major source of maintenance data was the computerized data base assembled by the Chicago Transit Authority and a similar (but not as complete) data base kept by Seattle Metro. In Phoenix, maintenance records were reviewed and interviews with the mechanics were conducted, but no on-board bus operating performance data were collected. Available data were tabulated, between site comparisons made, and where appropriate, simple statistical comparisons made between data on articulated and conventional buses.

In the economic analysis, extensive use was made of general cost and operational data from larger U.S. transit properties supplied by APTA as well as information on general operating procedures at transit properties obtained through contacts with transit property personnel. These data and information, as well as the operational and maintenance data collected at the articulated bus sites, were used to model and quantify the relevant cost streams encountered in purchasing both conventional and articulated buses. The cost analysis results were integrated with data on travel behavior subjected to a simple supply and demand analysis to identify and quantify the level of service impacts on passengers resulting from the use of articulated buses and to compare changes in user benefits with the cost impacts.

This report is divided into seven sections. Section 2 describes the design of the AMG/MAN bus in detail and the usage of these buses in U.S. cities at the time of the study. The results of analyses of run times and dwell times for articulated and conventional buses using the operating data collected in Seattle, Chicago, and Pittsburgh are presented in Section 3, along with a discussion of the relative passenger capacities of articulated and conventional buses. Section 3 also examines the maneuverability and handling capabilities of the articulated bus as well as the bus' accident and safety record. In Section 4, maintenance data from Chicago, Seattle and Phoenix, augmented by data which were sometimes available from other transit properties operating articulated buses, were examined to determine the differences in the nature and level of maintenance effort required for each bus type. Section 5 describes the analysis of the costs of articulated bus deployment, presenting the relative articulated and conventional bus unit costs and the costs incurred in operating articulated buses under different deployment scenarios. The level of service impacts on passengers from substituting articulated for conventional buses are identified and quantified in Section 6. These results and those from Chapter 5 are used to assess the benefits and costs of articulated buses in different contexts. Section 7 presents some concluding remarks and recommendations for further study.

## 2. DESIGN OF THE AMG/MAN BUS AND ITS USE IN THE UNITED STATES

### 2.1 Design of the AMG/MAN Bus

The MAN bus, pictured in Figures 2.1 and 2.2, is a three-axle vehicle powered by a uniquely-designed "pancake" engine, mounted under the floor just over the middle axle. The engine delivers its power to the middle axle, which drives the bus. The bus is built using what is known as monocoque body construction technique in which the sheet steel sides are heated and welded in place while they are still hot; when cooled, they shrink, providing tension and strength to the steel skin. A 55 foot bus is shown in Figure 2.1 and a three-door model of a 60 foot bus is shown in Figure 2.2. The 60 foot bus comes in either a 2 or 3 door model while the 55 foot bus comes in only a 2 door model.

Figure 2.3 shows a typical seating layout of a 55 foot·articulated bus in comparison to a conventional 40-foot GM bus. The obvious differences between this articulated bus and conventional bus are in length, number of axles, and the presence of a turntable (the "bending" portion) in the articulated bus. The articulated bus also has several other features which distinguish it from conventional buses. The front door widths on the articulated bus are 49" versus 36" for the conventional bus. The wider doors of the articulated bus offer the potential for faster loading and unloading and for simultaneous loading and unloading of passengers. The front-door step configuration of the articulated bus is different from the three-step conventional bus in that a fourth step is located several feet down the aisle beyond the fare box. This four-step configuration results in step riser heights which are smaller than those of conventional buses, which might make boarding articulated buses somewhat easier for some travellers. However passengers must still cope with a 14-inch vertical distance between the ground and the lowest step of the bus, as they must when boarding conventional buses.

A comparison of selected characteristics of the 55-foot MAN bus with a typical conventional bus is made in Table 2.1. As mentioned earlier, the American version of the AMG/MAN bus is different from the design manufactured by MAN for its European market. These differences resulted from the design specifications of the American consortium which deviated from the specifications MAN would normally employ. For example, the American version is slightly wider than its European counterpart (102" vs. 98"). The American version is heavier, due in part to the use of a heavier flooring material. The rear of the American model is squared, whereas the European model has a tapered rear. The doors of the American model open inward, with no protrusion beyond the outside plane of the bus; the European doors open outward and do not enter the stepwell. A major difference between the two buses is that the European model does not include an air conditioning system. The MAN bus is optionally equipped with a Trane air conditioning unit which is run by a separate diesel power plant (a Perkins 4-cylinder engine).

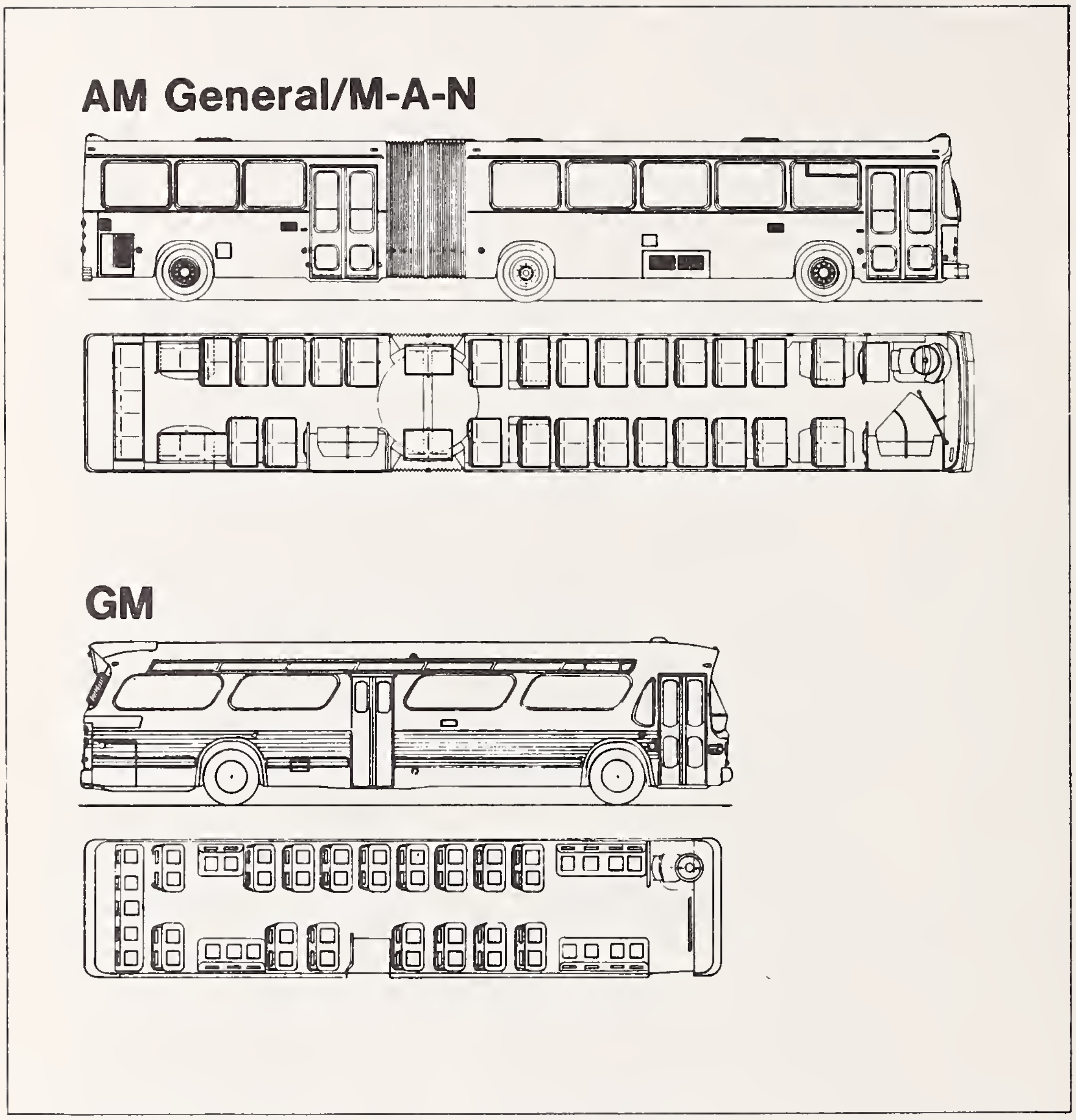
The braking system of the MAN bus is coupled with the transmission, such that, during the early stages of braking, the transmission is automatically employed as a "retarder" which helps slow the vehicle down before the air

FIGURE 2.1

<u>55-Foot AMG/MAN Articulated Bus</u>

FIGURE 2.2

<u>60-Foot AMG/MAN Articulated Bus</u>



SOURCE: Chicago Transit Authority, Operations Planning Dept.

FIGURE 2.3

Layouts of the AMG/MAN Articulated Bus and the GM "New Look" Conventional Bus

TABLE 2.1

Comparison of 55-foot MAN Bus with GM "New Look" Bus

| | AMG/MAN | GM "New look" |
|---|---|---|
| **Dimensions** | | |
| Length | 55' 5/16" | 40' 6" |
| Width | 8' 6" | 8' 5 3/4" |
| Weight | 36,400 lbs | 23,493 lbs |
| Door Width (clear opening) | 49.21" | 36" |
| Seats | 64-65 | 50 |
| Wheelbase | Tractor: 222 7/16" | |
| | Trailer: 255 1/2" | 284 3/4" |
| **Technical Data** | | |
| Turning Radius | 41' 4" | 42' 7" |
| Fuel Tank Capacity | 100 gallons | 125 gallons |
| Horsepower | 224 @ 2200 RPM | 239 @ 2000 RPM |
| Engine Displacement | 696.42 cu. in. | 567.0 cu. in. |
| Compression Ratio | 18.0 to 1 | 18.7 to 1 |
| Axle Ratio | 5.22 to 1 | 5 4/7 to 1 |
| Engine | 6 cylinder, horizontal inline, turbocharged 4 stroke | 8 cylinder, GM-8V-71N |

brakes are applied. The retarder was employed to improve brake life by reducing brake wear. A sophisticated computerized sensing mechanism is used to audit the loading upon each wheel and to differentiate the brake pressure at each wheel to compensate for varying passenger loads. The driver is supposed to be unable to distinguish different braking characteristics whether the bus is empty or full.

The articulated bus is equipped with 1200x20 tube type tires (load range H). Although many properties would prefer to use tubeless tires, a tubeless rim produced by a US manufacturer is not yet available in this size.

The joint venture of MAN with AMG resulted from the federal directive which requires transit operators to buy vehicles which are at least 51 percent American made. Production of the vehicle began in Penzberg, West Germany, where MAN constructed the basic shell of the articulated bus. The shell includes the basic running gear, air, electrical and hydraulics, driver's window, windshield and front door glass. The floor and all other windows were temporarily boarded up with plywood. The buses were then shipped to Houston and from there driven to AM General's Marshall, Texas facility. There, the interior fixtures such as the sidewalls, stanchions, heating, air conditioning, glass, lights and paint were installed.

MAN is opening a US plant in Cleveland, North Carolina, and in the future will manufacture and sell articulated buses (and other bus types) to the US market without joining forces with another US firm. As of this writing, the initial production of articulated buses from the plant is expected in August 1981. Peak production is anticipated in mid-1982 with a production level of 1.5 articulated buses per day.

## 2.2 Use of the AMG/MAN Bus in the United States

Over the past two years, transit operators in eleven U.S. cities have been using the AMG/MAN articulated bus. Table 2.2 lists the cities in which these articulated buses are in operation (as of November 1979), along with the number of articulated buses and the total number of buses in the transit fleet in each city. Since that time, other operators have also obtained or placed orders for these buses.

The AMG/MAN buses were acquired by a consortium of cities whose members varied somewhat through the history of the purchase. The operators listed in Table 2.2 represent the final consortium members with the exception of Seattle, which, because of the large number it wanted to order, acted independently to acquire its buses.

The consortium arrangement allowed individual cities to purchase a small number of buses for experimental use while making the total order large enough to justify the retooling by the European manufacturer required to produce a bus to American specifications. Articulated buses built by Ikarus, Volvo, and MAN were tested in US operation during the early 70's and final specifications were drawn up by the consortium based on this experience. The MAN bus was selected by both the consortium and Seattle, with AM General as the American dealer. MAN began producing drivable vehicles in Germany which were then

TABLE 2.2

US AMG/MAN Articulated Bus Fleets (as of November 1979)

| City | No. of Articulated Buses | Total Buses in Fleet | % of Artics |
|---|---|---|---|
| Seattle | 150 | 800 | 18.8% |
| San Diego | 44 | 320 | 13.8 |
| Washington, D.C. | 43 | 1,567 | 2.7 |
| Oakland | 30 | 628 | 4.8 |
| Los Angeles | 30 | 2,500 | 1.2 |
| Minneapolis | 20 | 856 | 2.3 |
| Chicago | 20 | 2,400 | 1.0 |
| Pittsburgh | 20 | 751 | 2.7 |
| Phoenix | 20 | 130 | 15.4 |
| Atlanta | 10 | 703 | 1.4 |
| San Francisco/ Marin County | 10 | 227 | 4.4 |
|  | 397 |  |  |

shipped to AM General, where seats, windows, air conditioning and electrical components were installed for final delivery to the US operators.

An in-depth review of articulated bus operations was made in Seattle, Pittsburgh, and Chicago, and, to a lesser extent Phoenix. Following is a description of the manner in which articulated buses have been used by each of these four transit operators, followed by shorter descriptions of the articulated bus experience in the other cities.

### 2.2.1 Seattle

In addition to the conventional diesel coaches, the Municipality of Metropolitan Seattle's (Metro) fleet of over 800 vehicles includes a number of small vans, electric trackless trolleys and 150 AMG/MAN articulated buses. Serving an area with a 1974 population of approximately 1.25 million, Metro operated 27.6 million bus miles in 1979. Metro's ambitious expansion plans call for more than 1600 buses to be in operation by 1985. Seattle has recently released a request for bids on 238 new articulated coaches; their planning target is to bring the Seattle articulated bus fleet up to a 1985 level of 538 -- 32 percent of the total vehicle contingent. The new articulated bus will include wheelchair lifts, a tapered trailer (the rear section of the bus), and other refinements to the current model.

Seattle generally enjoys relatively mild temperatures year-round. It rarely snows in Seattle, although the area is known for its rainy winter season. Cool temperatures in the summer have eliminated the need for air conditioning on Metro's bus fleet, significantly reducing both purchase price and maintenance costs. The city and surrounding area is quite hilly, necessitating the use of larger eight cylinder engines on standard coaches and restricting to some degree the routes to which articulated buses may be assigned.

Metro's service is currently assigned from five garages, two of which were recently constructed to accommodate articulated coaches. Two additional new garages are planned or under construction which will replace two older facilities. These new garages will also have maintenance, servicing and storage facilities designed specifically for articulated buses.

From the time they first took steps to acquire the high capacity articulated buses, Seattle Metro's management was convinced that the articulated buses should play a major role in the transit development plans for the city. Rather than acquiring a small number for initial testing, Metro decided to make a major purchase of the articulated coach based on the view that if they worked in Germany they would work in the U.S.

The articulated buses were first put into service on lines experiencing heavy loads during the peak hour. Several of the coaches were used to replace peak hour double headers (two buses running on the same schedule because of heavy loads) with a single articulated coach.

A second priority application for the articulated buses was to provide additional capacity and new service to the suburban park-and-ride lots. Metro found that the buses serving these lots were filled and that parking lot capacity was still unused. Faced with a limited budget, Metro concluded that for essentially the same operating cost, significant park-and-ride transit capacity increases were possible with articulated buses providing the service.

Based on their experience with the suburban service, Metro has concluded that the best use for the articulated buses is in peak hour express service on or near the region's freeways. About 125 of the coaches are used in this manner. The remaining 25 buses are used on heavily patronized local routes, again mostly in the peak hour. Because of the predominantly peak hour nature of their use in Seattle, the articulated buses tend to accumulate mileage at a slower rate than the rest of the Metro fleet.

The Metro scheduling department estimated that about one year was required to fit the entire 150 buses into the schedule. Approximately 75 buses were placed into use almost immediately, with opportunities for using the remaining 75 buses identified over a longer period of time.

Because of its commitment to the articulated bus, Metro feels it has been able to justify investment in maintenance facilities designed specifically for the vehicle. Two new bus garages, designed and equipped with the articulated bus in mind, along with a large parts inventory, have allowed Metro to repair and maintain their articulated buses more easily and effectively than the other operators. Continuous on-site support from a MAN technician has also aided in keeping Metro's articulated coaches on the road.

Metro pays its' drivers a 50-cent-per-hour premium for driving the bus. The motivation for the premium pay was to encourage a positive attitude toward the bus on the part of the drivers, rather than to overcome any specific problems with the transit union concerning the articulated buses.

### 2.2.2 Pittsburgh

The Port Authority of Allegheny County (PAT) operates nearly 800 buses and provides service to over 1.8 million people in the greater Pittsburgh area. One of the 15 largest transit operators in the country, PAT has acquired a fleet of 20 articulated buses, which began operation in February 1979.

The original intent of PAT's schedulers was to deploy the articulated buses on a number of heavily loaded and longer routes for a two week trial period and then to shift them to other routes with significant demand so that their use would be spread throughout the system. However, the schedulers believed that the articulated buses would carry such heavy loads that if they were to be removed for use elsewhere additional conventional buses would have to be added to the route. As a result, the articulated buses have not been replaced and still are run along the original routes. Occasionally, PAT officials will use the articulated buses for special events, such as serving the crowds at Three River Stadium for a Pirates game. PAT's manager of transportation feels that the articulated buses are good in this type of service in which demand is heavy and traffic is congested.

Another use of the bus occurred on a suburban/downtown express route which, though run at low headways over much of its route, operated at reduced frequency on the outermost leg of its run. The schedule department reported that they had often received complaints from riders wishing to go to destinations along the outer leg of the route who had been unable to board the crowded bus downtown. Consequently, they had to wait an extra hour for the next scheduled bus that would traverse the outer leg of the route. The articulated bus was used on this run to try to prevent such "denied boarding" situations from occurring, without scheduling an additional bus to control the heavy loading at the downtown boarding point.

Pittsburgh's topography is notoriously hilly, which has posed a special problem for the articulated bus. Management has therefore placed the articulated bus in service only where the routes have no steep grades. Garaging sites for the articulated bus were also determined, in part, on topography.

All PAT drivers are expected to be able to drive any PAT vehicle. Because the Manager of Transportation is an ex-driver himself, he is aware of the need to acquaint drivers with new equipment. He offers all drivers a paid three-hour training period during which an operator can drive the articulated bus with an instructor aboard--if need be--in actual traffic to become adjusted to its performance and handling. Three hours is one hour more than PAT normally allots to driver training on a new vehicle. In addition, for the first six months after the arrival of the articulated buses, drivers were provided with a "grace period" during which they would not be held accountable for improper handling of the vehicle relative to swing-out accidents.

### 2.2.3 Chicago

Chicago Transit Authority (CTA), with a fleet of over 2,400 buses, operates the third largest transit system in the country. Chicago operates their 20 articulated buses differently than do other operators studied during this project. Rather than assigning them to a limited number of routes, CTA has established a rotating schedule which places many of the articulated buses on different lines each day (although some of the buses are regularly assigned to the heaviest downtown routes). All types of service except high speed freeway express runs have been covered by the articulated buses, from heavily patronized central city runs, to less frequent crosstown services. This vehicle allocation method is designed to introduce the articulated bus to as many of CTA's patrons as possible, as well as to test the vehicle's performance in a variety of settings.

On Sundays and holidays, the articulated buses become "culture buses" serving three lines accessing museums and other cultural attractions. The buses are also used for promotions undertaken by CTA or for special events such as baseball games, Chicago fest, and events on the Navy Pier. One use for the buses in Chicago has been on narrow congested downtown routes with heavy ridership.

### 2.2.4 Phoenix

Like many of the others, the Phoenix Transit System has been using its 20 articulated buses on express runs. The buses have been in use since April 1979. Difficulty with climbing hills and maneuvering in traffic, along with repeated problems with the bus's air conditioning system, have limited the articulated bus' usefulness in Phoenix.

### 2.2.5 Oakland

AC Transit's 30 articulated buses have been in service for almost two years. Originally, the articulated buses were acquired with the goal of improving productivity on the slowest, heaviest local routes in the AC Transit system. AC Transit was familiar with the concept of articulated buses as they had been operating an articulated coach, originally built for Continental Trailways, since the mid 1960's.

Until all of the 30 buses were delivered to AC Transit and tested, the articulated buses on hand were used on a variety of local routes and in express service over the Bay Bridge between Oakland and San Francisco. When enough buses were available and drivers had been trained, the coaches were assigned to the longest and slowest local route in the AC Transit system, a route with heavy patronage and relatively high passenger turnover. This route was covered exclusively by the articulated coaches.

To take direct advantage of the buses' extra capacity, headways on the route were lengthened from 7.5 to 10 minutes and adjustments were made to account for the longer running times (because of increased dwell times with higher passenger loads per bus) required by the articulated bus to cover the route. A number of operating problems were encountered, including poor fuel economy, schedule adherence problems and passenger dissatisfaction. Further adjustments were made to the schedule but the articulated buses did not stay in service long enough to test the lastest version.

With the closing of the BART transbay tube after a serious fire in January 1979, AC Transit began diverting as much equipment as possible to transbay service. The articulated bus was a natural choice for providing the transbay service because of its high seating capacity. AC found that it could fill as many seats as could be provided on the services, and that the articulated bus was a heavily used vehicle. The use of the bus in transbay service has been viewed by AC Transit as successful from an operating standpoint.

Because the articulated buses were originally purchased with the intent of improving productivity on the heaviest and slowest lines in the AC Transit system, on which a lot of equipment and manpower is currently being used, the management is still anxious to test the bus in local service. They believe they can build on their brief past experience in effectively scheduling the larger bus on the high density lines and plan to put the bus back into local service once the need to provide extra transbay service has passed.

### 2.2.6 San Francisco/Marin County

The Golden Gate Bridge Highway and Transportation District (GGBHTD) originally purchased their 10 articulated buses for local collection and distribution of commuters using the high speed ferry service operated by the district between Marin County and San Francisco. However, technical problems reduced the capacity of the ferries, and the large buses were not required to serve the resulting low volume of ferry passengers. They were subsequently placed on a 27-mile suburban route with both city traffic conditions and a short highway segment. This application of the bus has increased public awareness of the District primarily because of the bus' sizw and novelty.

Although the district provides a great deal of transbay service over the Golden Gate Bridge to San Francisco, it does not plan to test the articulated bus in express service.

### 2.2.7. Los Angeles

The Southern California Rapid Transit District (SCRTD) has been using its articulated buses on two of its most heavily patronized lines--Wilshire and Hollywood Boulevards. On both routes, which experience heavy loads throughout the day, the articulated buses have been operating in mixed service with conventional coaches. Because of heavy transfer traffic to crosstown routes, as many as half the riders on the bus may get on or off at a single stop. The two rear doors, plus the double width front door (which allows simultaneous boarding and alighting) on the 60-foot bus used by RTD are thought valuable in handling this high passenger turnover.

No routing or scheduling changes were made on either line to accommodate the articulated buses. A direct one-for-one trade was made as the larger coaches replaced conventional buses in the schedule. RTD wanted to increase the passenger-carrying capacity on the lines since overloads were becoming a concern.

Some schedule adherence and bunching problems have been noted by RTD on the Wilshire and Hollywood lines. There is some indication that drivers prefer to drive other buses. The greater risk of accidents with articulated buses is thought to be the reason underlying this preference based on changes in driver picks.

The passenger and community response to the vehicles has been positive. Originally, the articulated buses were to be used exclusively on the Wilshire line. However, merchants on the Hollywood line insisted on having the buses serve their neighborhood as well, seeing them as a potential attraction for shoppers. A passenger survey indicated that the majority of RTD's passengers on the Wilshire and Hollywood lines preferred riding the articulated buses to conventional coaches. The passengers found them easier to board (despite the higher floor) and more comfortable.

### 2.2.8 San Diego

The San Diego Transit Corporation has been using its 44 articulated buses, the second largest articulated bus fleet in the country, on its three most heavily traveled routes, one of them a 20-mile run between the international border at Tijuana and downtown San Diego. Original plans called for this route to be covered by articulated buses exclusively, but in the first year following their introduction, maintenance problems limited their availability. With partial coverage by the articulated bus, ridership on the route has climbed from a previous day-long average of 86 passengers per trip to 97 since the articulated buses went into service.

The other two routes have experienced similar ridership increases. Officials at San Diego Transit believe that the articulated buses have allowed them to serve people who were being prevented from using transit by the lack of a place for them on a bus.

The larger passenger loads being carried on the articulated buses required that San Diego make minor schedule adjustments to accommodate the resulting slower operation of the bus. It was found that because of the higher patronage, the bus had lost three to five minutes relative to a conventional coach on an hour-long schedule. Consequently, bunching of conventional and articulated buses has been somewhat of a problem in mixed service during the peak hours. The schedule-maker in San Diego believes that as the drivers have become more accustomed to the larger bus, bunching has become less of a problem.

There are no immediate plans for expanding the use of the articulated bus to freeway express service. The San Diego Transit maintenance manager has recommended against their use in high speed operation because of insufficient power and some instability at freeway speeds. Steep hills on other routes in the San Diego area have also limited the use of the articulated bus to some degree.

### 2.2.9 Atlanta

The Metropolitan Atlanta Rapid Transit Authority (MARTA) has been operating its 10 articulated buses for nearly two years. They have been applied to routes with heavy loads where the maximum rush hour load was exceeding 170 percent of seaated capacity.

### 2.2.10 Washington

The Washington Metropolitan Area Transportation Authority (WMATA) has been using its 43 articulated buses on a single route where they provide all of the basic service. The route is of medium length with several branches and headways of 4 to 5 minutes. An exclusive bus lane is provided on the route through most of the congested downtown Washington area. This eliminates the need for the larger buses to maneuver around traffic and parked vehicles, a source of difficulty in some other applications of the articulated buses. Total passenger volumes on the route currently range from 80 to 100 passengers per trip, and the seating capacity of the articulated buses is generally fully utilized.

### 2.2.11. Minneapolis

The MTC began operating its 20 articulated buses in February of 1979.[1] At that time, total vehicle availability was affected by a recurring problem with the conventional bus fleet's transmissions. As a result, the articulated buses were initially used to help alleviate the chronic shortage of buses. To this end, articulated buses were deployed as substitutes, where possible, for conventional buses during peak-hours on a one-for-two basis. Conventional buses thus freed up were used to provide service in other areas. The articulated buses were also used to relieve specific overloads throughout the peak-hour schedule.

The MTC felt that substantial cost savings resulted from this one-for-two deployment policy due to the high service productivities that were achieved. It was also noted that maintenance costs of the articulated buses were much below the rest of the fleet, although direct comparisons were difficult since the articulated buses were used only for 4-6 hours per day, whereas conventional coaches saw much more use, and since other differentials existed (e.g., age, speeds, and so forth).

MTC reported that articulated buses deployed in peak-hour local service averaged approximately 10 percent more running time than conventional buses in that type service. In contrast, articulated buses used in express service were much better able to maintain schedule. MTC suggests that this difference may result from the difference in the number of stops that must be made for each type of service.

### 2.2.12. Concluding Remarks

Among the eleven cities, there does not appear to be any systematic pattern of deployment of articulated buses in revenue service other than the rather obvious usage of these buses at all sites on heavily loaded (often the most heavily loaded) routes. Rather, articulated buses have been utilized to provide a wide variety of transit services. Often, transit operators had not yet made any major adaptations in schedules or routes to take full advantage of the higher capacity of the articulated bus. However, there seems to be general agreement that special planning and scheduling efforts will be needed to realize the economic and service potential of articulated buses.

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[1] Metropolitan Transit Commission, "Cost Effectiveness Analysis of the First Year Experience with Articulated Buses," Minneapolis-St. Paul, February 1980.

# 3. OPERATIONAL AND SERVICE CHARACTERISTICS

## 3.1 Operational Characteristics

The operational characteristics of buses are important to transit operators and drivers and also can affect passengers' attitudes towards transit. The articulated bus, with its extra length and unique design, has operational characteristics which are, in some ways, quite different from those of a conventional bus. This study examined these operational characteristics through a synthesis of discussions with drivers of the articulated buses in each of the eleven U.S. Cities that have been using them over the past two years and through examination of limited data furnished by some of the eleven properties.

### 3.1.1 Maneuverability and Handling

Discussions with drivers of articulated buses in each of the cities provided insight concerning the maneuverability and handling of the vehicles and helped pinpoint specific problems associated with driving the bus. Often, drivers' comments were contradictory, especially with regard to their overall evaluation of the handling of the bus. For example, some drivers stated that they preferred to drive the articulated bus, while others said that they preferred the conventional bus. Some claimed the articulated bus was easier to steer, others that the bus was more difficult to steer. In short, such divided opinions often made it difficult to assess the driver's preference for one bus over the other. Perhaps the lack of unanimity is more a reflection of human nature on the subject of change than any intrinsic aspect of the bus.

This is not to say, however, that the articulated bus is without some discernible negative attributes. As previously noted, nearly all drivers felt that the bus lacked the power of the conventional bus. Drivers in Pittsburgh (which is particularly hilly) stated that engine power was insufficient for use on hills. This was especially a problem for an articulated bus entering an expressway from an up-graded ramp, where the lack of power makes it difficult for the bus to reach the speed of other expressway traffic. The results of experiments in Seattle using articulated buses with different gearing ratios than those of the regular MAN bus indicated that some of the problems originally attributed to "poor power" may really be due to non-optimal gearing. Nevertheless, several operators (including those in Pittsburgh and Minneapolis) are opting for articulated buses with more horsepower on their next order.

The poor acceleration of articulated buses on hills has been compounded by poor traction on wet or snowy roads. This had caused difficulties in getting the articulated buses to one of Pittsburgh's garages located in a hilly section. The operations manager mandated that snow tires be used year round on all articulated buses and that the front tires of all articulated buses be "siped".[1] This has apparently solved the problem of poor traction.

All indications are that during operation, the articulated buses are able to pull into and out from the bus stops without difficulty. No modification has had to be made to existing stops to accommodate the articulated buses in any of the cities visited.

A significant problem exists when the bus turns sharply. The bus actually has a tighter turning radius than does the conventional bus (41 feet versus 44 feet) and in this respect is actually more maneuverable on many streets than the conventional bus. However, to enable the articulated bus to make this tight turn, it has been equipped with a steering axle. This axle causes the rear end of the bus to swing out as much as 42 inches[2] during a tight turn. Thus when making sharp turns, the driver must take care that the tail-end of the bus does not hit parked cars, curbs or other objects. This has been a problem and has been a major cause of accidents. It is discussed in more detail in the next section.

Operators have responded to this problem in a variety of ways. Most have mounted signs on the rear of the bus to warn other drivers of the swing-out potential. Others have added rubber moldings to the rear edges of the bus to help protect both the bus and others. San Diego has reduced the steering ratio of the rear wheel to inhibit rear-end swing out. One driver notes that because of the vibration from the two engines on the bus (one for power, one for air conditioning) it can be difficult to detect collisions at the rear of the vehicle. As this can be a problem when the articulated bus is leaving or approaching a bus stop, the driver has suggested that a sensing device be mounted at the rear of the bus which would alert the driver that the rear of the bus is approaching the curb or some other object. It is instructive to note that the MAN articulated bus offered in Germany is configured with a tapered rear end to reduce the likelihood of swing-out collisions. The MAN bus evaluated in this report has a squared rear end because the members of the original American consortium desired the extra seating in the rear. Many operators who are re-ordering articulated buses are considering the advantages of the tapered end in the original design.

Because of its turntable and steering rear axle, the articulated bus is harder to operate in reverse than the conventional bus. Of all the things a driver new to the articulated bus must learn, reversing the vehicle is the most difficult. Moreover, a driver who improperly backs up the vehicle can damage the turntable mechanism or cause the brakes to lock, immobilizing the bus until a mechanic arrives. Fortunately, operators are not required to back up the bus very frequently.

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[1] Siping is the cutting of a tire across the normal tread to enhance its traction.

[2] As measured by instructors in Pittsburgh. MAN/AMG reported a nominal swing-out of 18" in the rear.

Driving the bus at high speeds, along express routes for example, does not pose a problem as long as the driver is aware of how the bus responds at these speeds. Unlike cars and conventional-sized buses, the articulated bus is sensitive to otherwise minor back-and-forth rotations of the steering wheel. This results from the steering rear-axle which is activated by the angular displacement of the turntable. Thus when the operator turns the steering wheel (and consequently the front wheels) to the right, the rear wheels will be turned automatically to the left. At high speeds this can cause the rear section to sway unless the driver keeps to a steady course. Drivers do not view this as a problem with the bus, but rather as a situation in which the articulated bus requires different handling than other buses.

Two other features that affect the bus' handling are worthy of note here: the electronic transmission and the brake retarder. The most pronounced effect of the articulated bus' electronic transmission occurs when a driver has stopped the vehicle, for example, at a stop light. When the vehicle is stopped, the automatic transmission on a conventional bus slips into first gear. The articulated bus' transmission slips into neutral. If the roadway has an uphill grade, the transmission of a conventional bus will keep it from rolling backwards, but on an articulated bus, the driver must apply the brake to hold his position. This is not a problem, per se, but it does require a change in the driver's operating habits.

The braking system of the articulated bus also behaves differently from that of the conventional bus. The MAN bus is equipped with a brake "retarder" as well as conventional air brakes. The retarder utilizes the transmission to help slow the bus down analogous to the way downshifting will slow down an automobile. The MAN's retarder is activated automatically by stepping upon the brake treadle. Many drivers have found this feature difficult to adjust to because the "feel" of the brake is different. When the brake treadle is first pushed--during the first third of its movement to the floor--the retarder is automatically brought into play. Unlike the bus' air brakes, however, which offer a resistance proportional to the pressure exerted on the pedal, the activation of the retarder does not offer such foot resistance. Since the only feedback the driver receives telling him that the "brakes" are working is the reduced speed of the bus (which is difficult to notice) the driver may assume that the brakes have not yet caught. Often when this happens, the driver will step more forcefully on the brake treadle, activating the air brake system sooner than necessary and thus reducing the effectiveness of the retarder system. This problem can be prevented with driver training programs that stress the design differences of the bus and the effects of these differences upon its operational characteristics.

### 3.1.2 Accidents and Safety

It is difficult to draw firm conclusions regarding the articulated bus' accident and safety record because of data and experience limitations. Discussions with personnel in each of the transit properties indicate that the bus is more prone to accidents than the smaller conventional bus and that this was particularly true during the early period following its introduction to the fleet. These people believe a high percentage of the bus' accidents result from the tendency of the rear-end to swing out during turns, so one might expect their overall accident rate to be higher simply because a conventional bus does not experience this problem. Data for quantifying the magnitude of this difference, however, have been difficult to obtain.

Figure 3.1 illustrates accident data for a seven-month period in Phoenix for 20 articulated buses. A comparison of these data with those of Phoenix's recently acquired fleet of 37 RTS-II buses illustrates the consistently higher accident rate per vehicle-mile for articulated buses, 7.7 accidents per 100,000 miles for articulated buses versus 3.8 for the RTS-II's on average.

The Metropolitan Transit Commission (Minneapolis-St. Paul) reports that its 20 articulated buses averaged 17.1 accidents per 100,000 miles whereas their conventional buses averaged only 5.3.[3] Interestingly, of the 60 accidents involving articulated buses in Minneapolis-St. Paul, all but four occurred while turning. It should also be noted that nearly every operator uses articulated buses exclusively during peak periods. This makes direct comparison more difficult because it is not possible to adjust these per mile figures to reflect increased vulnerability to accidents during congested periods.

The Legal Department at Pittsburgh's Port Authority has not reported an increase in the frequency of claims resulting from use of the articulated buses.

### 3.2 Service Characteristics

The service characteristics of the articulated bus are a critical determinant of its attractiveness to both the transit industry and to transit users. For this reason, our study devoted considerable effort to collecting and analyzing data for assessing articulated bus service characteristics relevant to operators and passengers, particularly passenger carrying capacity and in-service run time. Actual performance data collected on board articulated buses in Chicago, Pittsburgh, and Seattle were analyzed in detail. Additional data were obtained either directly from other transit operators with articulated buses or through information reported by operators in recent trade journal articles. Floor plans of articulated and conventional buses furnished by Chicago Transit Authority and by MAN were used in calculating the passenger carrying capabilities of the two types of buses.

#### 3.2.1 Passenger Carrying Capacity

A crucial aspect to be considered when examining the relative cost effectiveness of articulated and conventional buses is their respective passenger carrying capacities. Physical characteristics to be considered in

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[3] Metropolitan Transit Commission, "Cost-Effectiveness Analysis of First-Year Experience with Articulated Buses at the Twin Cities," Minneapolis-St. Paul, February 1980.

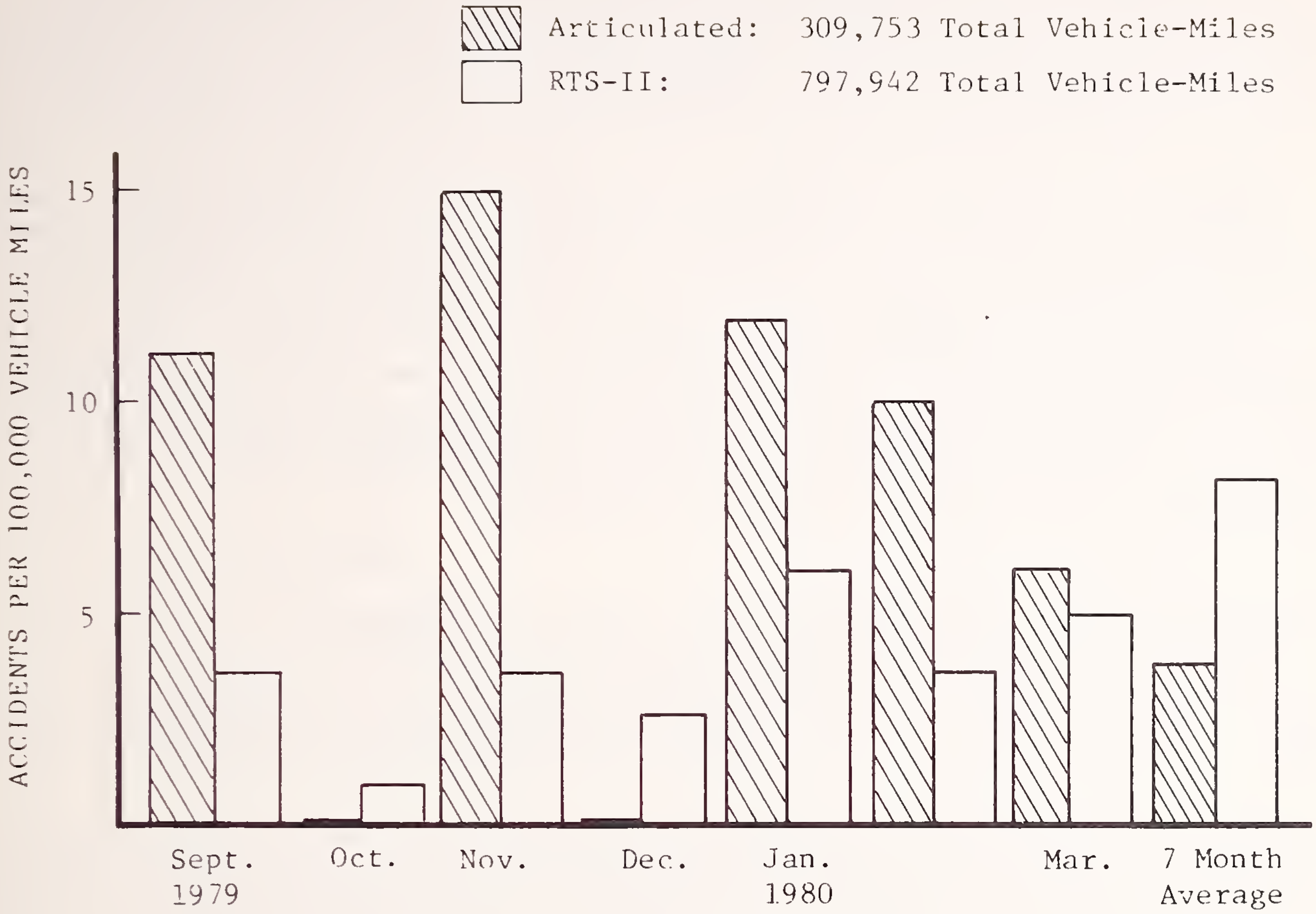

FIGURE 3.1

Accidents (per 100,000 vehicle-miles)- MAN/AMG Articulated and GM RTS-II Buses, Phoenix, Arizona determining capacity include the amount of available floor space, the numbers of doors and their configuration, the method by which fares are collected and its nature (e.g., fare box and/or pass, fixed or zone fare, tokens or cash, and so forth), the numbers of seats, door opening and closing time, and numbers of stairs to be negotiated. Human factors to be considered include the propensities of passengers with respect to moving to the rear of the bus, sitting or standing, toleration of crowding, time to negotiate stairs and to make fare payments, and like matters. Moreover, the manner and extent to which bus space is utilized for standees probably will be affected by the length of the passengers' trips and the amount of hand baggage. All of the above (and perhaps other) factors combine to set a limit on the number of people which a bus can carry; thus, they determine its capacity.

Capacity, then, should represent the expected number of people which can be carried for situations in which more passengers wish to board the bus than can actually be loaded onto them (i.e., at least one potential rider must be refused entry because the bus is full). Using this definition, adequate data are not available for determining bus capacity. Rather, the more widely published and quoted figures are based on mere estimates or adopted standards. Moreover, such numbers vary considerably from source to source and contain values for the number of standees that are not consistent. Below, for instance, are sets of published data for two types of buses, the conventional 40-foot GM bus and the 55-foot MAN articulated bus.

| Source of Data | GM 40-ft. | | MAN 55-ft. | |
|---|---|---|---|---|
| | No. of Seats | Standees | No. of Seats | Standees |
| • UMTA[4] | 53 | 38 | 65 | 33 |
| • DeLeuw, Cather[5] | 53 | 14 | 52 or 64 | 25 or 23 |

Note the large differences between the two sources both in the total number of standees and the relative number of standees on the GM and MAN buses.

Faced with the lack of satisfactory data on capacity, this study used a simple method for calculating bus capacities. With this method, bus capacity is the sum of the number of seats and an estimate of the potential number of standees. The latter quantity was allowed to vary with alternative estimates of standing room space per standee. Also addressed was the resultant percentage of total passengers who would be standing for each bus type.

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[4] Urban Mass Transportation Administration, U.S. Department of Transportation, New Bus Equipment, Washington, DC, January 1981.

[5] DeLeuw, Cather and Company, Comparative Analysis Study of Alternative Transit System for the South Hills Corridor, Report to Port Authroity of Allegheny County, PA, March 1976.

Calculations were done based on the layouts used by the Chicago Transit Authority, in which the 55-foot MAN vehicle has 65 seats and about 125 square feet of standing area and the GM vehicle has 50 seats and about 85 square feet of standing area,[6] and from the blueprints furnished by MAN in which the 60 foot bus has 71 seats and about 150 square feet of standing area. The results are shown in Table 3.1.

As can be seen from the table, the capacity of the 60-foot MAN bus is estimated to be 106-124 passengers, of whom 35-53 are standees. This capacity estimate is approximately 50% higher than the estimate for the 40-foot GM conventional bus, which is 70-80 passengers including 20-30 standees. The 55-foot MAN bus' estimated capacity of 94-109 passengers, including 29-44 standees, is about 35% greater than that for the GM conventional bus. The ranges in the number of standees arise from varying the amount of standing room per standee on each bus type between 2.83 and 4.25 square feet. Note that for each value of standing room per standee, the percentage of passengers seated is roughly equivalent for the two bus types. However there is a slightly larger percentage of standees for the articulated buses. Based on these estimates, we conclude that the capacity of two 60-foot MAN buses is roughly equivalent to the capacity of three conventional buses, and that three 55-foot MAN buses and four conventional buses have roughly equivalent capacities.

### 3.2.2 In-Service Run Time

Differences in in-service run times between articulated and conventional buses on the same route can have considerable impacts on both passengers and operators. Passengers riding the articulated buses will experience changes in level of service and operators deploying these buses may need to alter schedules and modify route fleet requirements.

In our first round of discussion with each of the articulated bus operators, several of them reported that, because of the lower horsepower and larger size of articulated buses, they presumed that there would be difficult in keeping the articulated buses to schedules originally developed for conventional coaches, especially on routes with short headways. This expectation was reinforced by a recent article on articulated buses in Motor Coach Age[7] which reported that articulated buses require ten percent more operating time on routes in Calgary, Canada. Drivers in Seattle, Chicago, Pittsburgh, and Phoenix concurred in this point -- the articulated buses lacked the power they were accustomed to in a conventional bus -- and therefore they expected that it would be difficult to hold to schedule.

In the face of this limited evidence, our study undertook the collection of considerable data on routes on which both articulated and conventional

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[6] Square footages computed from layouts shown in Figure 2.3.

[7] Hamm, V.G., and B.E. Sullivan, "Articulated Buses - The Alberta Experience." Motor Coach Age, Volume XXXII, No. 3.

## TABLE 3.1

### Relative Capacities of Articulated and Conventional Buses at Equal Passenger Comfort Levels

| | MAN 55-Foot Bus | | | | MAN 60-Foot Bus | | | | Conventional 40-Foot GM | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Standing Room per Standee* | No. Seats | No. Standees | Total Pass. | % Seated | No. Seats | No. Standees | Total Pass. | % Seated | No. Seats | No. Standees | Total Pass. | % Seated |
| 2.83 | 65 | 44 | 109 | 60% | 71 | 53 | 124 | 57% | 50 | 30 | 80 | 63% |
| 3.39 | 65 | 37 | 102 | 64% | 71 | 44 | 115 | 62% | 50 | 25 | 75 | 67% |
| 4.25 | 65 | 29 | 94 | 69% | 71 | 35 | 106 | 67% | 50 | 20 | 70 | 71% |

*Square feet of standing room per standee buses were operated. Using this data, the two components of in-service run time -- between stop running time and dwell time -- were analyzed separately, and the results of these analyses then combined to draw conclusions on total in-service time.

### 3.2.2.1 Between Stop Running Time

All of the operators interviewed during this study reported that the AMG/MAN bus lacks the acceleration capability of a conventional bus. On theoretical grounds, this is to be expected. According to MAN's specifications, the articulated bus' 6-cylinder turbo-charged engine develops 224 horsepower whereas the engine supplied with conventionally-sized buses can sometimes develop more. (For example, older 8-cylinder GM developed 239 horsepower.) So, together with its already greater empty vehicle weight and greater potential passenger loads, the lower horsepower of the MAN bus could be expected to offer less acceleration than a conventional bus.

Preliminary results from Calgary Transit, illustrated in Figure 3.2, show operating speed profiles for 55- and 60-foot MAN buses (European version) versus a 6-cylinder T6H-5307N GM bus when both were tested on an abandoned airstrip (All three of these buses were out-performed by the Flyer 800 bus, which, while equipped with a 6V-71 GM diesel engine, benefits from the higher performance of a Spicer automatic transmission). These results would indicate that the MAN bus falls behind the GM bus as higher speeds are approached, but that there is not much real difference in acceleration at typical local street speeds (20 to 30 mph).

The Metropolitan Transit Commission in Minneapolis-St. Paul, reports that their articulated coaches accelerate at the same rate (0 to 30 mph in 0.11 mile) as a 6-cylinder conventional bus and at about three-fourths the rate of an 8-cylinder conventional bus when the air conditioner is not in operation.[8] When the air conditioner unit is operating, however, the difference in acceleration between the articulated bus and the conventional 8-cylinder bus is reduced by a half, since the unit on a conventional bus is operated off its propulsion engine while an articulated bus employs a separate engine to power the air conditioner.

The discussion above refers to operating speed performance in an unconstrained environment. To examine operating speeds in actual operating situations where traffic, speed limits, and driver's judgment constrain speed performance, stop-to-stop running time data was collected by on-board checkers in both Pittsburgh and Chicago and for both articulated and conventional buses. In Pittsburgh, only bus runs that "matched" were used. In other words, data was used only if there was data for both an articulated bus and a conventional bus on the same route, on the same day, and scheduled within one hour of each other. Chicago's more limited data base precluded complete matching, but the principal of using matched pairs of data was followed as much as possible.

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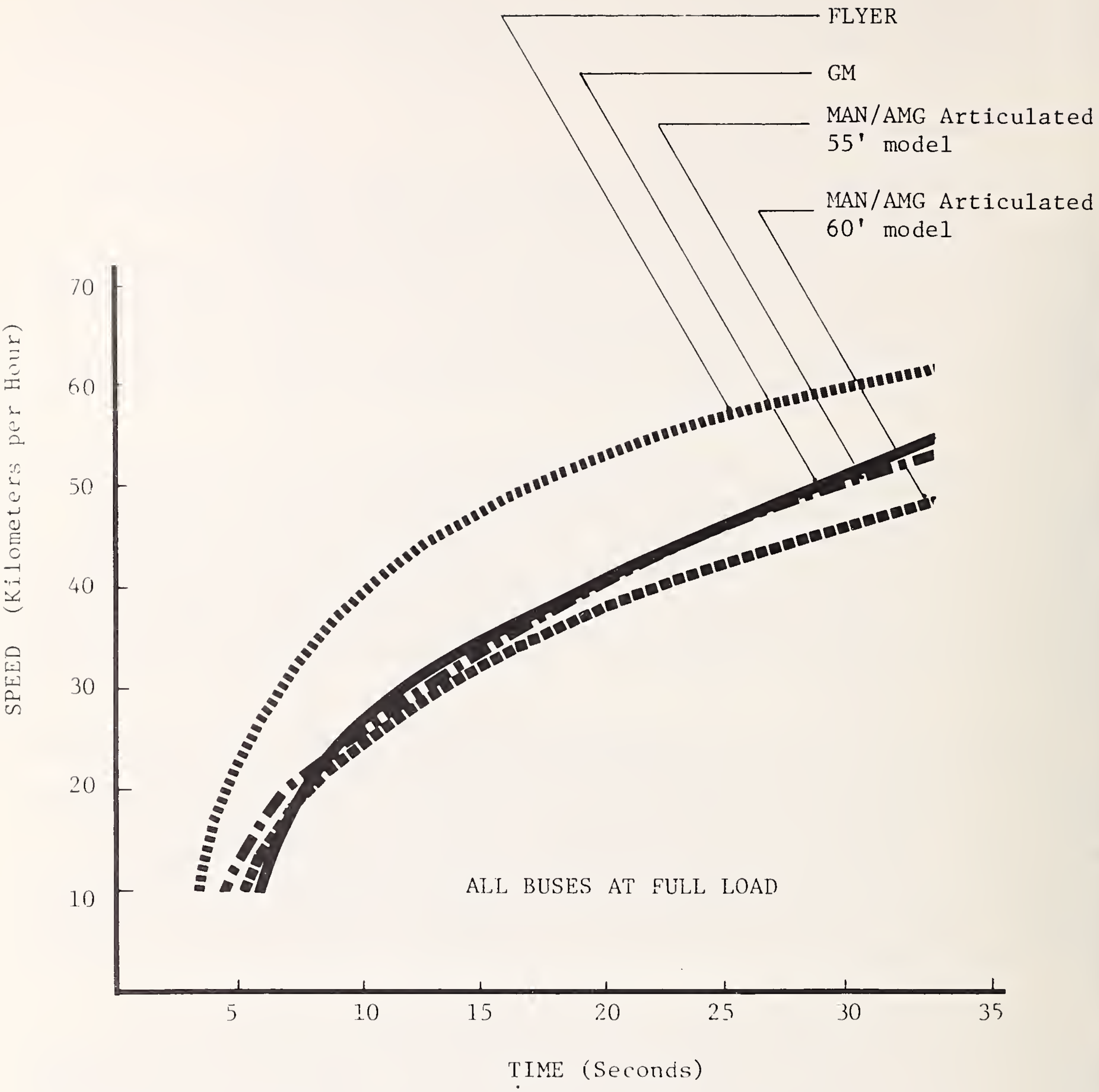
[8] Metropolitan Transit Commission, op. cit.



SOURCE: Motor Coach Age Vol. XXXII No. 3, "Articulated Buses - The Alberta Experience" by V. G. Hamm and B. E. Sullivan

FIGURE 3.2

Comparison of Speed Characteristics for Articulated and Conventional Buses

Travel times were compared for transit trip segments stratified by their lengths and the mean travel time and standard deviation were calculated, both expressed in minutes. For example, in Pittsburgh, in the 0.15-0.20 mile range, there were 400 articulated bus observations which averaged 0.87 minutes to travel betwen stops. For the same distance, 558 conventional bus observations showed an average running time of 0.92 minutes, slightly longer than for the articulated bus. In Chicago, for the same distance interval, the conventional bus was slightly faster than the articulated bus -- 0.92 minutes for the conventional bus versus 1.03 minutes for the articulated bus.

In any case, the results are less than conclusive. For instance, in Pittsburgh, the conventional buses were slower in 15 out of the 20 mileage intervals (and in all but one interval their variance was higher as well), while in Chicago the reverse tended to hold true; that is, for mileage intervals of 0.8 miles or less the articulated buses were slower in nine out of 16 cases and their variance was higher in 13 of the 16 intervals. While the hypothesis that conventional and articulated bus travel times are not significantly different cannot be rejected at the 95% confidence level, the variance in all of the travel time intervals leads us to view any statement derived from the data with considerable caution.

The tentative conclusion, using all of the available data and observations is that, in general, prevailing traffic controls and traffic conditions, driver habits, and speed limits dictate running times between stops, not the type of bus. Short stop spacings would suggest high density of development and likely heavy traffic conditions, so that traffic and traffic lights would likely be the controlling factor at this end of the spectrum. Long station-spacings would likely occur in lower density areas where speed limits might control. Either way, any difference in power between the articulated bus and the conventional bus is dominated by external factors, and there is little difference in operating speeds (exclusive of dwell times) between the MAN articulated bus and a conventional bus.

Further analysis of the Pittsburgh and Chicago running time data failed to reveal other factors which could explain differences in running times. In particular, the greater weight and potential passenger loading did not appear to adversely effect the articulated buses' running times. Running times had no significant positive correlation with the number of passengers on board the vehicle, for example.

Strictly speaking, the conclusion from the data that the MAN bus operates at speeds indistinguishable from those of a conventional bus applies only to local routes operating in areas without major hills or significant turns. The effect of hills or sharp turns on running times was not analyzed for lack of data and it is suspected that operators have avoided assigning articulated buses to routes with these characteristics. Also, the above conclusions cannot be stated for express routes with equal confidence because comparable express route running time data was not available for analysis.[9] Nevertheless, discussions with drivers in Seattle confirm that articulated buses operating on freeways do not have a problem keeping to schedule.[10] In addition, the Metropolitan Transit Commission in Minneapolis-St. Paul even goes so far as to state that articulated buses operating in express service appear to adhere better to schedules developed for conventional coaches. Logic suggests that, while an articulated bus may take longer to get up to the speed limit on a freeway, this is a small amount of time in comparison to the amount of time traveled at the speed limit. In all likelihood, then, overall travel speeds on express routes are also not appreciably different for the two buses.

#### 3.2.2.2 Dwell Time

A second component to be considered when analyzing the in-service run time of articulated buses is dwell time. Dwell time is the service time associated with passenger boardings and alightings at a given stop. The data collected in Seattle, Chicago, and Pittsburgh was used to analyze the passenger service times. On-board checkers counted passenger boarding and alighting activity (by door) at each stop and measured the dwell time as well. For measurement purposes, dwell time was defined as the time interval from the opening of the first door at a stop to the closing of the last door. Checkers were told to stop timing if passenger activity ceased for more than 15 seconds, regardless of the door positions. (Unfortunately, this arbitrary timing procedure introduces a systematic bias which leads to an underestimate of the unloading times; also, in those cases when fares are collected when passengers alight, one would expect this bias to understate the alighting times for articulated buses more than those for conventional buses.)

The results of the dwell time analysis ran counter to operators' initial expectations. Many operators a priori expected that the wider doors and the shorter step configuration of the MAN bus would increase the speed of passenger boarding and alighting, often permitting two streams of passengers to be processed at once. Drivers, however, remarked that the doors on the MAN bus were slower to open and close than those of conventional buses. The analysis shows that this latter factor seems to dominate. In addition, observations of passenger boarding patterns during the data collection effort indicated that passengers frequently failed to utilize the wider doors of the articulated bus.

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[9] Seattle operates articulated buses in express service and on freeways, but distance (between stops) data was not available for this analysis.

[10] Seattle drivers are more concerned with the safety aspects of the articulated bus on hilly Seattle's freeway. The articulated bus' poor hill-climbing ability is a weakness. Because of it, the articulated bus may pose a hazard to other vehicles when entering a freeway on an uphill-graded on-ramp. Newer models of the articulated bus have substantially greater horsepower than those studied here.

Because of the potential importance of dwell time differences between the articulated bus and conventional bus, the dwell time data was analyzed to provide an explanation of any significant differences. Statistical models described in Appendix A were developed to relate dwell time to boardings, alightings, the number of passengers using the rear door, the payment of fares, the presence of both boarders and alighters at the same door at the same stop ("interaction"), and the door opening and closing times.

From the model results it was found that the articulated bus can process passengers slightly faster than the conventional bus once the doors are open (i.e., coefficients of boarding and alighting are slightly smaller for the articulated bus than for the conventional bus). However, the difference (7 to 15) percent) is small in comparison to what might be expected with the articulated bus' double-width doors. While passenger volumes at many stops may be too small to warrant the use of two streams of traffic through the articulated bus' doors, it would appear from the data that very little of this is being done at any stops, so that the faster loading/unloading potential of the articulated bus is not being fully realized. On-site visual observations of articulated bus operations, albeit limited, corroborate the data and this conclusion. It should be noted that fare payment and collection methods can have a large impact on per passenger processing time. The statistical models tried to quantify this effect but were unable to do so because of insufficient data and relatively little variation in the manner of fare payment.

The model results given in the Appendix have been plotted (for Pittsburgh and Seattle, as well as a composite of the two) in Figures 3.3, 3.4 and 3.5.[11] All three show that the door opening plus closing times (y-intercept) are longer in the articulated bus than the conventional bus -- 6.5 seconds versus 4.0 seconds. A separate timing of the doors of each bus confirmed this result. The slopes of the lines in all three figures are nearly identical; using the composite data in Figure 3.5, the marginal service times are 1.68 seconds per boarder or alighter for the articulated bus and 1.89 seconds per boarder on alighter for the conventional bus. Thus, while the articulated bus takes longer to open and close its doors, it can load or unload additional passengers somewhat more quickly. However, the passenger processing time advantage of the articulated bus is so small that it does not offset its slower door speed until there is an average of 12 boardings plus alightments at a stop. For boarding plus alightment activity of less than 12 passengers at a stop, the conventional bus is faster, for greater than 12 passengers at a stop, the articulated busis faster. The simple equations for dwell-time (in seconds) at a stop are as follows:

- Dwell Time For Articulated Bus = 6.45 +1.68 (B&A)
- Dwell Time for Conventional Bus = 4.02 +1.89 (B&A)

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[11] Chicago dwell time data was felt to contain too many errors to be presented in this discussion, so it was dropped after statistical tests confirmed this (especially for the conventional bus data).

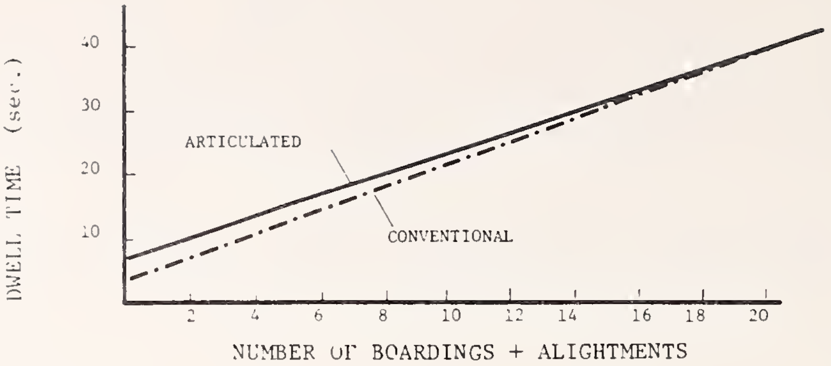

FIGURE 3.3

Pittsburgh - Dwell Time per Stop vs. Boardings + Alightments

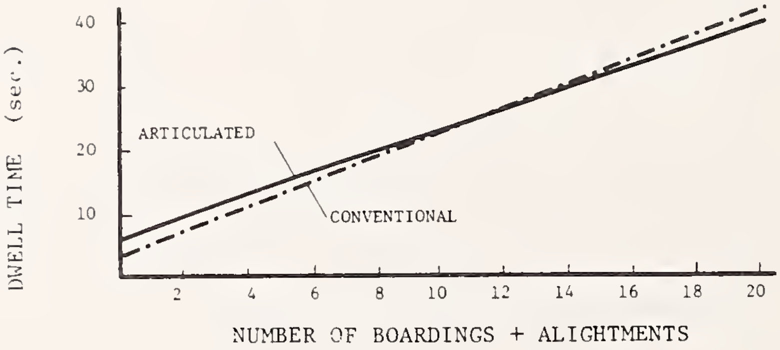

FIGURE 3.4

Seattle - Dwell Time per Stop vs. Boardings + Alightments

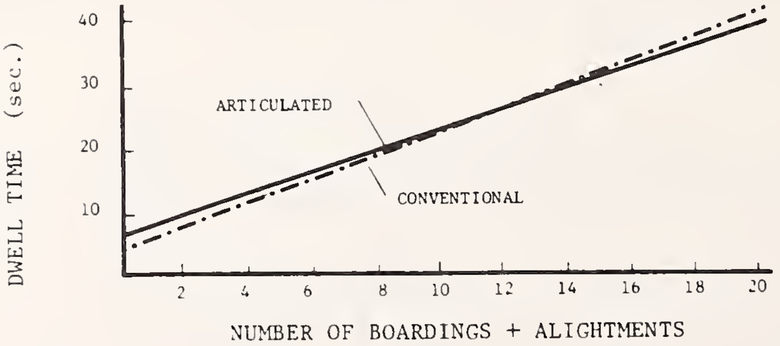

FIGURE 3.5

Composite - Dwell Time per Stop vs. Boardings + Alightments where (B&A) is Boardings plus Alightments

Using these models plus area-specific data to provide values for rear-door activity and the interaction variable, expected total dwell time on bus routes of a given number of stops and given passenger volume were computed. Table 3.2 shows the results of these calculations for Pittsburgh and Seattle.

It can be seen that on an average route (40 to 60 actual stops) an articulated bus will require one to two minutes longer dwell time than a conventional bus when the two buses operate under comparable passenger volumes. However, on a run with a larger number of stops (for example, 100) the difference in dwell time can approach four minutes.

In all likelihood an articulated bus would be used to carry more passengers than the conventional bus it is replacing. Table 3.2 shows that, for example, if an articulated bus were to carry an additional 50 passengers, dwell times would increase up to 3 minutes as a result only of boarding and deboarding the 50 additional passengers. This extra dwell time is in addition to the extra dwell required on an articulated bus to board and deboard the same number of passengers as on a conventional bus. These dwell time estimates can be used to judge the effects on bus bunching of replacing conventional buses with articulated buses and the requirements for adjustments to the schedule.

### 3.2.2.3 Conclusions on In-Service Run Time

Differences in in-service run times between articulated and conventional buses are due mainly to higher articulated bus dwell times. Dwell times, which are dependent upon door openings, passenger processing time, and passenger loading, are longer for articulated buses even given equal passenger loads. Higher loads on many articulated buses will increase articulated bus dwell times further. Differences in running time between stops for articulated and conventional buses do not appear to be large or significant. However, this conclusion may be biased by the fact that operators have not used articulated buses on routes where these differences could be significant.

The analysis has shown that, on an average route (40 to 60 actual stops), an articulated bus will require one or two minutes longer than a conventional bus to complete the same run when they operate under comparable volumes and on streets that are not hilly. However, on a run with a larger number of stops (for example, 100), the difference in travel time can approach four minutes, which may have significant impacts on operators and passengers. The 1-4 minute difference for an average route is due primarily to the longer period of time taken for opening and closing doors on the articulated bus -- 6.5 seconds for the articulated bus per stop versus 4 seconds for a conventional bus. When it is taken into account that the articulated bus will often carry considerably more people than a conventional bus, the additional dwell time associated with servicing the additional passengers plus the possibility of the bus making more stops to pick up the additional passengers can add up to an additional 3 minutes onto dwell time. The end result is that total in-service travel time on an articulated bus will be 1-7 minutes greater than for a conventional bus, depending on route characteristics and passenger volumes.

## TABLE 3.2

## Expected Dwell Times, In Minutes, As a Function of Number of Stops and Passenger Volumes

### Pittsburgh Data

| | No. Actual Stops | Passenger Volumes (Total Boardings) 75 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|
| Articulated Bus | 20 | 6 | 8 | 9 | 10 | 12 | 13 | 14 |
| | 40 | 8 | 10 | 11 | 12 | 14 | 15 | 17 |
| | 60 | 10 | 12 | 13 | 14 | 16 | 17 | 19 |
| | 80 | 12 | 14 | 15 | 17 | 18 | 19 | 21 |
| | 100 | 14 | 16 | 17 | 19 | 20 | 21 | 23 |
| Standard Bus | 20 | 6 | 7 | 9 | 10 | Beyond the Loading of a Standard Bus on Most Routes | | |
| | 40 | 7 | 8 | 10 | 11 | | | |
| | 60 | 8 | 9 | 11 | 12 | | | |
| | 80 | 9 | 11 | 12 | 14 | | | |
| | 100 | 10 | 12 | 13 | 15 | | | |

### Seattle Data

| | No. Actual Stops | Passenger Volumes (Total Boardings) 75 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|
| Articulated Bus | 20 | 6 | 8 | 9 | 11 | 12 | 14 | 15 |
| | 40 | 9 | 10 | 12 | 13 | 14 | 16 | 17 |
| | 60 | 11 | 12 | 14 | 15 | 17 | 18 | 19 |
| | 80 | 13 | 15 | 16 | 17 | 19 | 20 | 22 |
| | 100 | 16 | 17 | 18 | 20 | 21 | 22 | 24 |
| Standard Bus | 20 | 6 | 8 | 9 | 11 | Beyond the Loading of a Standard Bus on Most Routes | | |
| | 40 | 8 | 9 | 11 | 12 | | | |
| | 60 | 9 | 11 | 12 | 14 | | | |
| | 80 | 11 | 12 | 14 | 15 | | | |
| | 100 | 12 | 14 | 15 | 17 | | | |

Generally, these differences in in-service run times would be expected to be smaller for express routes, on which the total number of stops, boardings, and deboardings are relatively low, and greater for local routes, on which the number of stops, boardings, and deboardings tend to be higher.

Because of longer articulated bus in-service run times, the use of articulated buses in mixed service with conventional buses on the same high frequency routes may exacerbate bus bunching problems. Particularly where the per-stop passenger on-off activity is high, bunching problems become worse because of the longer dwell times of articulated buses, which could cause an articulated bus to fall further and further behind a conventional bus scheduled directly ahead of it, and might result in a conventional bus scheduled directly behind an articulated bus to catch up with it. It is possible that changes in schedules and operating strategies could reduce the frequency and severity of bunching but this is a matter for future investigation.

It should be noted that the conclusions reached in the above section are not independent of existing operating practices and that this fact could result in different conclusions being reached concerning articulated bus in-service run times in other situations. As one example, fare payment and collection methods can have a large impact on dwell times. However, it was not possible to quantify this effect in our statistical analysis because of insufficient data and because of relatively little variation in the manner of fare payment. There is reason to believe, however, that other methods of fare payment, such as self-service fare collection, which make it possible to take greater advantage of the articulated bus' double width doors, would lead to considerably reduced boarding and alighting times for articulated buses relative to those for conventional buses.

# 4. MAINTENANCE EXPERIENCE

This section describes the maintenance experiences that transit operators have had with the articulated bus. The conclusions regarding the maintenance experience were drawn from observations made during informal discussions with foremen, mechanics, and repairmen as well as from data collected and reported to the study team by transit operators themselves. The analysis of the maintenance experience of the articulated bus is limited, however, by several factors. First, since the bus has only recently been introduced to this country, some of the maintenance activity can be attributed to the "breaking-in" which accompanies any new vehicle. Some of these problems are chargeable directly to the bus's warranty and thus do not impact the operator's maintenance costs. Ideally, comparisons of maintenance rates between different vehicles should take warranty repairs into consideration. Unfortunately, warranty claims are included in the maintenance records and cannot be separated from non-warranty service in the analysis. Second, evaluating the working life of individual components was also.impossible in many instances because of their relatively long life and the vehicle's brief operational history: most components simply have not yet been in use for a sufficient length of time to permit a component life evaluation.

A third limitation of the analysis is the confounding effect of the use of service personnel provided without additional charge by the manufacturer. In every site visited, AMG/MAN had stationed a field representative full-time for one year to help in the repair of articulated buses.[1] The field representative was an experienced technician, familiar with all aspects of maintenance associated with the articulated bus and he proved to be invaluable to the operators. His services were paid directly by MAN (AMG had local field representatives visit on a part-time basis) and were not included in the accounting of mechanics hours at each property. Unlike the inclusion of warranty repair data, which tends to inflate a new vehicle's measures of maintenance effort, this factor causes maintenance efforts to be understated. The net effect of these influences, however, is not known and the data presented below have not been adjusted for either of these factors.

## 4.1 Maintenance Overview

Before discussing specific maintenance issues, it is informative to describe how the maintenance crews who were contacted viewed the articulated bus. The mechanic's view of a bus is often biased because he deals exclusively with the vehicle's problems. It therefore should not be surprising that he describes a vehicle in terms of these problems. Care must be taken to weigh these opinions against objective, comparable measures for other vehicles before judging the maintenance experience with articulated buses.

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[1] Some sites were able to gain longer stays for their field representatives.

### 4.1.1 Pittsburgh

In Pittsburgh, all mechanics must be able to repair any type of bus; specialists are used only for air conditioning repair work. In comparing the articulated bus to other buses, the day foreman at one of the garages said that the articulated bus appeared more solid and that it was "built to last." Mechanics felt that the access to various components was good, especially for components of the electrical system. For example, small side doors that flip open provide ready access to the articulated bus' head lamps.

Mechanics in Pittsburgh reported that the articulated bus required no more time than a conventional bus for similar repairs. For example, the foreman reported replacing an articulated bus' transmission in nine hours, which is comparable to the time required for that type of job on a conventional bus.

For Pittsburgh, the biggest maintenance problem on the articulated bus was the systems of belts driven by the engine. The belt system includes the pulley, brackets, and three belts. Pittsburgh' standard procedure for replacing the articulated bus's belts is to replace all three of them when one fails. This is done because it is a four-hour job to replace a belt and to realign the brackets and pulleys properly. According to the foreman, it makes sense to replace all belts rather than risk a premature failure of another belt.

The mechanics believe that brake maintenance is more frequent on the articulated bus, citing a brake relining frequency of every 14,000 miles on average. The brake's automatic slack adjuster is quite good, and they have come to rely on it. In comparison, the automatic brake adjuster on Pittsburgh's conventional buses was disengaged and adjustments were made manually because it was functioning so poorly.

The signage in all articulated buses has been inoperative since the second week of service. Although the four signs on the vehicle are supposed to be controlled by a single switch, only the sign at the front of the bus can be kept operational.

Routine maintenance is performed upon each bus on a similar schedule. All buses receive oil changes every 8,000 miles. Transmission fluids are replaced and vehicle lubrication applied at 24,000-mile intervals. Vehicle mileage is estimated from fuel consumption, and a computerized system alerts the garages to preventative maintenance required by vehicles as they approach the threshold mileage point.

A minor servicing problem exists in Pittsburgh because of the shared locations of the water and oil pumps at the garage service islands. While this allows the conventional buses to be serviced adequately, it causes a problem for the articulated buses because the articulated bus' access to water is from the right side, while its oil is accessed from the left. Despite this, the crews reported that the bus takes no more time to wash or to fuel than does a conventional bus.

Overall, the mechanics interviewed in Pittsburgh found the articulated bus to be no better or no worse than a conventional bus from a maintenance standpoint.

### 4.1.2 Seattle

Maintenance personnel at Seattle's South and East Base said that they'd "rather have two forty footers than an artic." However, they also said that the coach was "very sturdy." The biggest problems with the articulated buses, as cited by Seattle's maintenance crews have been drive belts, electrical problems, molding on the seat platform above front axle, transmission problems, and turntable damage when backing the bus.

According to both supervisors interviewed, although the mechanics have now "reached the top of the learning curve" for articulated buses, comparable tasks still take more time to finish on the articulated bus. Trouble-shooting and repairs both take longer. Seattle maintenance staff cite the greater number of parts and somewhat greater difficulty in doing tasks as the primary reasons for the increased time required. However, this is not thought to apply when comparing the articulated bus with the newest Flyer and AMG standard buses. In this instance, the articulated buses compare more equally because the newest buses are more complex than the older "new look" buses.

Seattle operates its routine maintenance program with slightly different schedules for each bus type (see Table 4.1). While the articulated bus has a more frequent schedule for changing the oil and air filter, its fuel filter schedule change is somewhat longer. An important advantage of the articulated bus is that it does not require a 1,000 mile safety check of its brakes because, as reported in Pittsburgh, it is equipped with automatic slack adjusters that really work.

### 4.1.3 Chicago

As a matter of policy, Chicago provides a higher level of maintenance for its articulated buses than it normally provides for its other coaches. This is due to the frequent use of the bus as a public relations and promotional tool for the transit authority. For example, whenever a special function of municipal dignitaries requires the use of a bus, one of CTA's 20 articulated buses will be given the assignment. Consequently, when an articulated bus is diagnosed as having a problem, it receives prompt and full attention.

The Chicago maintenance crew considered the MAN bus to be extremely well constructed and gave the bus high marks in general for its ease of maintenance. They did, however, mention several problem areas. Fluid changes were required more frequently on the articulated bus. For example, the transmission required transmission fluid changes every 12,000 miles, while a GMC's was changed every 36,000 miles. Wheel alignment on the articulated bus was a recurring and time consuming problem. To compound the problem, special optical equipment was needed as a guide to align the wheels of the articulated bus, whereas a conventional bus could be aligned in ten minutes with only a

TABLE 4.1

Seattle's Scheduled Intervals for Routine Maintenance

| | Conventional Bus | Articulated Bus |
|---|---|---|
| Oil Change | 12,000 miles | 4-6,000 miles |
| Fuel Filter | 2 @ 12,000 | 1 @ 12,000<br>1 @ 18,000 |
| Air Filter | 12,000 | 4,000 |
| Slack Adjustor Safety Inspection | 1,000 | Not Required[1] |
| Brake Inspection | 2,000 | 2,000 |

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[1] Automatic Slack Adjustors make 1,000-mile inspection unnecessary on artics.

steel rod.[2] Diagnosing transmission problems has also been a problem, requiring two to four hours for even the simplest of problems. CTA reports that these and other problems necessitate an assignment of between seven and ten repairmen to the articulated fleet every day.

### 4.1.4 Phoenix

The maintenance director of Phoenix Transit System is unenthusiastic about the articulated buses. From his perspective, they represent an additional maintenance burden because of their unique character. Their parts inventory is greater and they require special metric tools. He does not believe that mixing bus types in a fleet is necessarily a good policy from a strictly maintenance point of view. Nevertheless, he believes they are well-constructed and he cites the fact that they do not leak oil, as his RTS-II's are prone to do. He also remarks that his mechanics, once trained to work on the articulated bus, actually prefer working on it to working on other bus types.

The Phoenix maintenance director has assigned three mechanics full-time responsibility for Phoenix's fleet of 20 articulated buses. They work only on articulated buses. Aside from the air conditioning system which, as in most cities. has been a major maintenance problem, the mechanics reported few recurring problems. Their number one problem, they felt, was the system of belts throughout the bus, which seemed to need constant adjustment. Tire wear seemed poorer on the articulated buses, and from the pattern of wear, it appeared to be an alignment problem. Cleaning and washing of the bus was more time consuming because Phoenix's cyclone vacuum (which is normally attached only at the front of the bus) lacks sufficient power to be used on the articulated buses because of their longer lengths.[3] In addition, fueling the bus was somewhat slower.

## 4.2 The Major Maintenance Problems Cited for Articulated Buses

### 4.2.1 Air Conditioning Problems

The air conditioning system is American made and installed by AMG in the United States. In spite of the fact that bus air conditioning units have been in existence for a very long time, this particular unit has had many problems. Each of the transit authorities contacted has stated that the installed A/C unit breaks down too frequently. When asked, "what problems are you having with the articulated bus?", the air conditioning unit was almost invariably the first item mentioned.

Phoenix had to abandon use of its AMG/MAN's for three months in the summer of 1979 due to its high frequency of air conditioning failure. The

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[2] Chicago is the only site of the four that required these special tools.

[3] This was not a problem with the vacuums in other cities.

cause of the failures was related to Phoenix's special climate of hot temperatures and lack of wind. Normally, the hot air from the main engine is exhausted under the bus. In other cities, the occasional breeze will disperse the heat. In Phoenix, however, breezes are infrequent and the heat tends to build up. After sitting in one spot for a while, if the bus makes a left-hand turn, its A/C air intake will pass directly over a stagnant mass of very hot air, which, when sucked into the already stressed A/C system, adds to its burden and causes the A/C to shut down entirely. The problem was solved when a rubberized baffle was installed which prevented the air under the bus from entering the A/C air intake. None of the other operators have had to make this modification to their bus, however. The manufacturer was studying revisions to the design of the air conditioning system and is expected to offer a newer version in future bids.

### 4.2.2 Turntable Problems

The articulated bus, as with any vehicle with a trailer, can be "jack-knifed" if improperly driven. The rear wheels accentuate the tendency to angle because they turn opposite to the direction of the front wheels. It is especially difficult for a driver to judge the amount of rear wheel steering when he is backing up the bus. The manufacturers were aware of this problem, and placed two sets of switches on the turntable to help prevent turntable damage. The first switch warns the driver with a buzzer and flashing light that the angle is becoming too sharp. The second locks the brakes if the angle grows any sharper--before, it is hoped, damage can occur to the turntable.

Experience with these devices has shown that they have not always been effective in preventing turntable damage. Although there was very little data to quantify the incidence of turntable damage, the problem has been severe enough to encourage several operators to modify the switches to better prevent its occurrence.[4] Atlanta hooked up a sensor to the reverse gear which produces an automatic radio call to the dispatcher. The dispatcher queries the driver, and, if he is not fully qualified on the vehicle, he is instructed not to back up the vehicle. Chicago concluded that the cam which activates the braking switch was too short, and was being jumped due to the bus' momentum when the jack-knifing occurred too quickly. They lengthened the cam to assure lockup. Another transit authority repositioned the switches to provide earlier driver warning but this also shortened the permissible angle before a brake lockup would occur.

### 4.2.3 Belts

As mentioned previously, all operators reported difficulty keeping the belt and pulley systems used in the articulated bus' pancake engine, as well as in the air conditioner's engine, properly adjusted. It was apparent that

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[4] In a review of maintenance data for 150 articulated buses from Seattle during the period January 4, 1980 to March 14, 1980, repairs to turntables were made four times with an average repair time of 1.8 days each.

some of the problems resulted from the mechanics' unfamiliarity with belt systems of this type, as the engines of American-made buses do not employ belted components to the degree that the articulated bus does. Nevertheless, it must also be concluded that much of the problem with the belts resulted from the belts themselves. The manufacturer is currently trying to resolve this problem by repositioning mounting brackets and by utilizing belts made of different material. In fairness, however, it must be noted that operators have reported similar problems with the belts found in the air conditioning system of the newer Grumman 870 Advanced Design Bus.

### 4.2.4 Parts: Cost, Availability and Inventory Requirements

Parts availability and cost has been a problem for every operator. Most operators report that the magnitude of the problem has been reduced since the early period of the articulated bus' use for two reasons. First, operators have learned what parts are likely to fail and how many of each part is required in inventory to be able to meet parts needs and to accommodate long ordering lead times. Second, parts which earlier were available only from German manufacturers have begun to become available from manufacturers in this country. This has reduced both price and required lead times for ordering.

When discussing parts, it is important to differentiate between the American-made components and those manufactured by German suppliers. The American-made parts, which are used for such things as the air conditioning, lighting, fixtures and windows tend to be comparably priced to similar components on conventional buses. The German-made parts, which constitute most of the running gear of the bus, are imported and furnished to the various transit authorities through AMG. They are about twice as expensive as comparable parts on American-made buses.

Sometimes an operator has been able to reduce this differential simply by comparison shopping. For example, Seattle mentioned that a simple brake block rivet costs 40 cents for the German-made version, but that a Japanese manufacturer offers a comparable rivet for 16 cents. Chicago reports that, on the average, the price for smaller parts is fairly similar to those for conventional-sized American-made buses; larger parts tend to be more expensive. However, there are parts which are exceptions to this rule of thumb. For example, Chicago's maintenance department compared the $25 cost of a GM shock absorber to the $300 cost charged by AMG for the articulated bus's shock absorber. Similarly, they noted, a new transmission for a GM bus cost about $7,000; the articulated bus' costs about $25,000.

Parts availability has varied by transit authority. Seattle acquired a large parts inventory which alleviates some of their problems, but adds to their overall expense.[5] Seattle cites a poor record of parts delivery for the articulated bus and, because of it, they carry twice the stock normally required for a domestic bus. They have found that domestic parts suppliers

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[5] In Seattle, the parts stock for articulated buses averages $4,000 per coach. For standard buses it is $1,500.

can deliver within 30 days, while the imported parts take three times that long. However, they have noticed that local parts sources are springing up, and they expect this to reduce the problem.

In a graphic example of how parts costs can be reduced, Seattle reports that the articulated bus' air filter, which cost them more than $100 when purchased through AMG, was available for $45 from a local importer. Their cost was further reduced when they identified a local parts manufacturer who was willing to rebuild the filter for less than $19. They are currently negotiating with a local manufacturer to build new filters that would sell for less than $23.

This phenomenon is occurring elsewhere as well. For example, San Diego stated that an oil filter from AMG for their articulated bus cost $90, but that a local manufacturer has begun offering the same filter type for between $35 and $40.

One other factor contributes to the need to maintain a larger inventory of parts for the articulated bus. Many of the parts that are inventoried for the various models of conventional bus can be shared among the different buses. This is especially true of buses that have the same engine type. For example, Phoenix, which had already ordered 37 RTS-II buses, reported that if 20 RTS-II buses were ordered instead of 20 articulated buses, their parts inventory would have increased only marginally. Articulated buses, because they are so different, cannot share parts with other buses. This tends to raise the size of the parts inventory required by the articulated bus.

## 4.3 Analysis of Repair Records--The Chicago Maintenance Experience

There was limited maintenance information available for rigorous analysis, compounded by differences in methods of accounting and form of data from one property to the next. However, Chicago had a wealth of maintenance data available in machine-readable format which greatly facilitated a comparative analysis of the articulated and the standard buses. Accordingly, it was decided to focus the maintenance analysis on Chicago, and only introduce information from other operators where there was a data gap or contradictory or inconclusive findings.

### 4.3.1 Frequency of Repairs

CTA provided complete maintenance data on its fleet of 20 articulated buses and 20 of its 1976 vintage GM "new look" buses. The fleet of 1976 GM buses was used as the basis for comparison as they were the newest vehicles CTA operated and it was thought desirable to compare the newly acquired articulated buses with the next newest bus available. The 1976 GM's perform much better than the "average" CTA bus with regard to maintenance cost. In fact, in FY79 CTA reported an average of 28 cents per mile for maintenance of the 1976 GM fleet, but an average of 40.5 cents per mile for all its vehicles. Over the same period, the articulated bus averaged 60 cents per vehicle mile for maintenance. These relative costs should be kept in mind when reviewing the results that follow. These data covered the eight-month period between

November 1, 1979, and June 30, 1980. Although the articulated buses were first introduced in Chicago in March 1979, it was felt that using only the most recent eight-month period would help to avoid the inclusion of any undesirable effects attributable to "breaking in" the articulated bus.

The comparison of the repair records for the two groups of buses is summarized in Table 4.2. All repairs have been assigned to 1 of 19 possible VMS repair categories.[6] Each group of buses is accounted separately. The first two data columns show actual numbers of repairs for each type of bus. The last two columns show the same information normalized to a per-bus, per-100,000 miles basis since the actual articulated bus usage was only 384,400 miles versus 571,300 miles for the conventional GM buses.

In terms of total repairs, the articulated bus fleet experienced 2,052 versus 1,337 for the conventional bus test group, some 50 percent more than the conventional buses. After adjusting for vehicle mileage, this difference is even more dramatic--534 repairs per articulated bus per 100,000 miles versus 234 repairs per conventional bus per 100,000 miles, a 128 percent greater repair requirement for the former. In only two categories--brakes and convertors--did the articulated bus experience significantly fewer repairs. Far and away the most significant maintenance problem with the articulated bus has been the air conditioning/heating system, which accounts for 23 percent of the requisite repairs excluding preventative maintenance. The articulated buses have also undergone 129 percent more preventative maintenance trips to the shop.

Four other categories with a statistically significant number of observations in which the articulated bus compared unfavorably to the conventional bus are the air system (over seven times as many repairs), the bus interior (more than double the repairs), the electrical system (over three times the number of repairs), and tires and wheels (two and a half times the number of repairs). If preventative maintenance is excluded from the analysis (on the grounds that it may be more precautionary than necessary) and if air conditioning/heating system repairs are likewise excluded (on the grounds that future versions of the AMG/MAN articulated bus will have corrected the problem), the articulated bus still shows 86 percent more repairs required per 100,000 miles than the GM conventional bus, as shown in the subtotal of Table 4.2

The preceding discussion was based on aggregate problem groups. While this is useful for identifying general problem areas, it may be less than revealing. For example, in Table 4.2, Category 19 (Doors) could reflect the fact that one type of bus is having a minor problem with door hinges while the other may be experiencing major problems with control relays. However, in trying to disaggregate this data further, the frequency of occurrences may be so small that it is statistically impossible to distinguish when the two repair figures are truly different.

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[6] VMS is CTS's "Vehicle Maintenance System."

TABLE 4.2

Incidence of Repair by Maintenance Category for 20 AMG/MAN Articulateds and 20 1976 GM Buses during the Period November 1 1979 through June 30, 1980

| VMS Repair Category Code | Repair Category | Number of Repairs | | Repairs per Bus Per 100,000 Miles | |
|---|---|---|---|---|---|
| | | GM-1976 (50 Seats) | AMG/MAN-1979 (64 Seats) | GM | AMG/MAN |
| PM | Preventative Maintenance | 560 | 864 | 98.0 | 224.8 |
| 11 | A/C and Heat | 47 | 270 | 8.2 | 70.2 |
| 12 | Air System | 28 | 145 | 4.9 | 37.7 |
| 13 | Brakes | 35 | 11 | 6.1 | 2.9 |
| 14 | Bus Exterior | 98 | 98 | 17.2 | 25.5 |
| 15 | Bus Interior | 96 | 139 | 16.8 | 36.2 |
| 16 | Chassis and Suspension | 28 | 32 | 4.9 | 8.3 |
| 17 | Convertor | 69 | 28 | 12.1 | 7.3 |
| 18 | Cooling System | 42 | 35 | 7.4 | 9.1 |
| 19 | Doors | 72 | 39 | 12.6 | 10.1 |
| 20 | Electrical | 43 | 93 | 7.5 | 24.2 |
| 21 | Engine | 24 | 35 | 4.2 | 9.1 |
| 22 | Fuel and Exhaust | 26 | 53 | 4.6 | 13.8 |
| 23 | Lights | 78 | 49 | 13.7 | 12.7 |
| 24 | Lubrication | 9 | 26 | 1.6 | 6.8 |
| 25 | Signs | 34 | 50 | 6.0 | 13.0 |
| 26 | Steering | 0 | 1 | 0 | 0.3 |
| 27 | Tires and Wheels | 45 | 78 | 7.9 | 20.3 |
| 31 | Communication | 3 | 6 | 0.5 | 1.6 |
| | Subtotal excluding Preventative Maintenance and Air Conditioning | 730 | 918 | 127.8 | 233.8 |
| | All Problems | 1,337 | 2,052 | 234.0 | 533.8 |
| | Thousands of Bus-Miles | 571.3 | 384.4 | | |

Data: Courtesy of Chicago Transit Authority

In an attempt to further pinpoint particular repair problems, a Chi-square statistical test of significance was performed at the most disaggregate level of reporting available from Chicago's data. Table 4.3 lists the maintenance subcategories where the articulated bus has required significantly more maintenance and those where the articulated bus has required significantly less maintenance by this criteria.

As can be seen, the problems with the articulated bus' air conditioning system result from the failure of many parts rather than an isolated few. The refrigerant, the controls and wiring, the generator belt, the high/low pressure switch, the modulating water valve, the condensor coil, and the discharge line are all problems. In the same general category, the heater core has an abnormal number of problems, and there are other problems (unspecified) with either the air conditioner or the heater.

The GMC has a significant problem with its rear doors, and various problems with other elements. Although there are significant problems with the convertor as a whole, only three individual components show up as having excessive maintenance frequencies: the fluid lines, filters, and governor. Together, these items make up only 28 of the 69 occurrences in the GMC aggregate convertor goup. A similar relationship holds in the brakes group, where the brake relay valve accounts for only 7 of the 35 general occurrences.

An eight-month observation period is too short to completely assess a vehicle's maintenance history,.but it does provide some measure of the problems and their magnitude.

Is this worse repair record for the articulated bus solely or mainly attributable to its newness? If one examines repair records by month over the period that CTA has had their articulated buses, can any noticeable improvement be seen? Table 4.4 shows the total number of shop repairs for each test group for each month over the eighteen months that CTA has had their articulated buses. The middle pair of columns shows thousands of bus-miles driven by each type of bus, and the final pair of columns shows the (normalized) number of repairs per 1,000 miles per month. The averages at the bottom of the two right-hand columns repeat the same finding: overall, the articulated bus required more than double the number of shop repairs required by the conventional bus, 5.67 per 1,000 miles versus 2.30 per 1,000 miles. The frequency of repairs is quite consistent for the GM bus over time; if one ignores the first three month's worth of data for the articulated bus, its frequency of repair record is likewise fairly consistent--more variation from one month to another, but no discernible pattern of a decreasing number of repairs as time goes on. This latter result is shown graphically in Figure 4.1.

Based on the foregoing Chicago data, the following conclusions on frequency-of-repairs record can be drawn: The articulated buses are brought into the shop for repairs more than twice as often (128 percent more) as conventional buses per 100,000 bus miles.

TABLE 4.3

Repair Subcategories Indicating Significantly Different Repair Frequencies

| VMS Repair Category Code | Repair Category | Number of Repairs<br>GM-1976 (50 Seats) | <br>AMG/MAN 1979 (64 Seats) |
|---|---|---|---|
| ELEMENTS WHERE THE ARTICULATED BUSES HAVE SIGNIFICANTLY MORE REPAIRS | | | |
| 27 | Tires Replaced | 35 | 74 |
| 12 | Air System Belts | 0 | 53 |
| 11 | A/C Refrigerant | 6 | 37 |
| 11 | A/C Controls and Wiring | 2 | 35 |
| 20 | Alternator Belt | 0 | 34 |
| 11 | Ventilator and Controls | 4 | 33 |
| 12 | Auto Drain Valve | 1 | 33 |
| 11 | A/C and Heat (unspecified) | 5 | 31 |
| 11 | Heater Core | 3 | 31 |
| 11 | A/C Generator Belt | 1 | 15 |
| 22 | Fuel Filters | 2 | 13 |
| 20 | Switches | 1 | 13 |
| 12 | Alcohol Evaporators | 0 | 13 |
| 22 | Fuel Hoses and Fittings | 0 | 11 |
| 11 | A/C Hi/Lo Press. Switch | 0 | 10 |
| 11 | Modulating Water Valve | 0 | 10 |
| 14 | Body Glass, Repair | 0 | 10 |
| 11 | A/C Condensor Coil | 0 | 9 |
| 12 | Check Valves | 0 | 9 |
| 21 | Air Cleaner Element | 0 | 8 |
| 11 | A/C Discharge Line | 0 | 7 |
| | Thousands of Bus Miles | 571.3 | 384.4 |
| ELEMENTS WHERE THE GM BUSES HAVE SIGNIFICANTLY MORE REPAIRS | | | |
| 19 | Rear Doors (and Linkage) | 32 | 8 |
| 15 | Horn Assembly | 19 | 3 |
| 14 | Skirt Panel | 13 | 1 |
| 17 | Fluid Lines (Convertor) | 12 | 2 |
| 12 | Air Dryer Assembly | 11 | 0 |
| 17 | Transmission Assembly | 11 | 0 |
| 17 | Filters (Convertor) | 9 | 0 |
| 13 | Brake Relay Valve | 7 | 0 |
| 17 | Governor (Convertor) | 7 | 0 |
| | Thousands of Bus-Miles | 571.3 | 384.4 |

TABLE 4.4

Chicago's Maintenance Experience with 20 AMG/MAN Articulated Buses Versus 20 1976 GM Buses over Time

| | Actual No. Shop Repairs | | Thousands of Bus-Miles | | Repairs per 1,000 Miles | |
|---|---|---|---|---|---|---|
| Month | GM | AMG/MAN | GM | AMG/MAN | GM | AMG/MAN |
| 1/79 | 178 | 1 | 50.1 | NA | 3.55 | NA |
| 2/79 | 165 | 16 | 57.3 | NA | 2.88 | NA |
| 3/79 | 162 | 244 | 79.9 | 18.7 | 2.03 | 13.05 |
| 4/79 | 165 | 238 | 65.6 | 51.4 | 2.52 | 4.63 |
| 5/79 | 173 | 258 | 63.8 | 46.2 | 2.71 | 5.58 |
| 6/79 | 167 | 219 | 73.9 | 47.4 | 2.26 | 4.62 |
| 7/79 | 143 | 256 | 63.3 | 34.6 | 2.26 | 7.40 |
| 8/79 | 128 | 307 | 64.1 | 39.2 | 2.00 | 7.83 |
| 9/79 | 128 | 277 | 73.3 | 50.0 | 1.75 | 5.54 |
| 10/79 | 169 | 230 | 66.4 | 46.5 | 2.55 | 4.95 |
| 11/79 | 172 | 181 | 65.7 | 43.7 | 2.62 | 4.14 |
| 12/79 | 116 | 139 | 74.3 | 44.5 | 1.56 | 3.12 |
| 1/80 | 151 | 192 | 62.2 | 41.6 | 2.43 | 4.62 |
| 2/80 | 150 | 199 | 63.6 | 38.8 | 2.36 | 5.13 |
| 3/80 | 150 | 255 | 85.3 | 47.9 | 1.76 | 5.32 |
| 4/80 | 189 | 319 | 67.0 | 36.3 | 2.82 | 8.79 |
| 5/80 | 151 | 284 | 68.7 | 38.0 | 2.20 | 7.47 |
| 6/80 | 174 | 255 | 84.5 | 57.6 | 2.06 | 4.43 |
| TOTAL | 2831 | 3870 | 1228.9 | 682.4* | 2.30 | 5.67* |

*Excludes 1/79 and 2/79

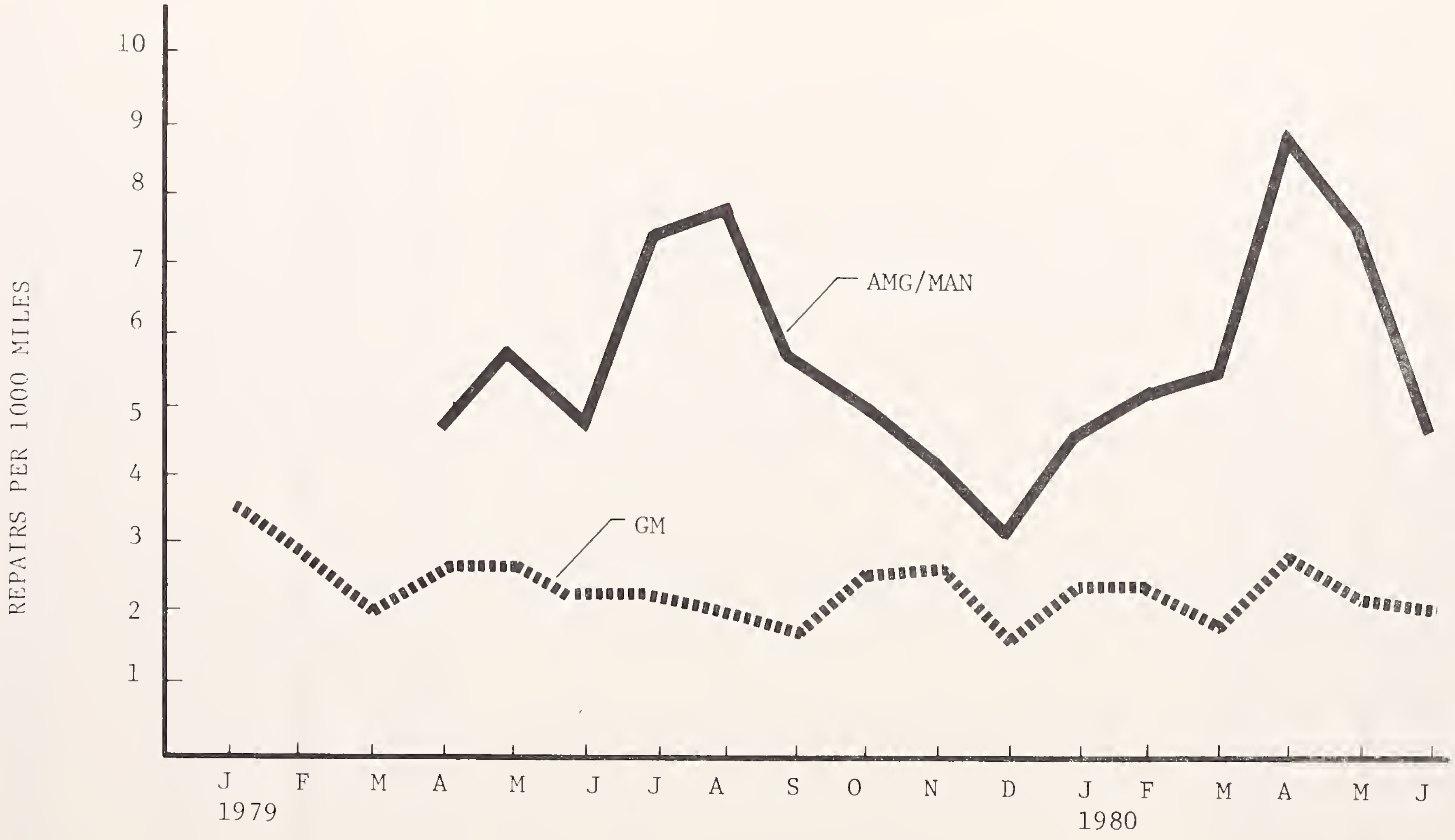

FIGURE 4.1

Chicago Maintenance Experience: Frequency of Repairs over Time for 20 AMG/MAN Articulated Buses vs. 20 1976 GM Buses

### 4.3.2 Labor Requirements for Repairs

In addition to the frequency of repairs required, another important factor in determining bus maintenance costs is the number of labor hours needed to perform each repair. Unfortunately, data regarding the labor expended on maintenance was not readily available in a format which would permit a direct comparison between articulated buses and conventional buses except in Chicago. Other sites have provided maintenance labor cost data, but this data was of limited usefulness because it was not broken down by maintenance category.

Table 4.5 repeats Chicago's most recent eight-month repair records (number of repairs by category) for each type of bus. Alongside, it also shows the average labor hours per repair for each category. Overall, the articulated bus averaged 2.9 hours per repair versus 2.2 hours per repair for the GM conventional bus, or about 32 percent more. Removing the one major steering repair (13.4 hours) from the articulated bus record does not alter the 2.9 hour average figure.

The finding that the articulated bus repairs take longer is perhaps not surprising given that the articulated bus is a new type of vehicle; a mechanic or repairman will require some time to become familiar with articulated bus repairs. However, Chicago's experience does not show any improvement over time as indicated in Figure 4.2. Even with air conditioning and heat system repairs excluded, the articulated bus's monthly mechanic hours per thousand bus miles has not decreased over the eighteen months of articulated bus operation. Figure 4.3 presents the same information with air conditioning and preventative maintenance removed. It further reinforces the same point. Nevertheless, CTA has a small number of articulated buses and a relatively large number of mechanics, so much of this may still be attributable to becoming familiar with the articulated bus. Also, the higher repair time of the articulated bus in Chicago may not hold up on other properties where the articulated bus constitutes a higher proportion of the fleet and repairmen are given more regular exposure to the special techniques of troubleshooting and repairing the articulated buses.

### 4.3.3 Vehicle Availability: Service Outages for Repairs

Since the articulated bus has required more repairs than the older GM buses and the average repair has taken longer, one would expect that the articulated bus would have more service outages (less availability) than the conventional bus. In Chicago this was indeed the case, although the manner in which their maintenance records were processed did not yield a usable "number of days out of service" figure.

Some of this is undoubtedly attributable to the mechanics' lack of familiarity with the articulated bus repairs, as previously mentioned. It may also be partially attributable to the age difference; the older GM buses may have had any general design quirks and individual idiosyncrasies all worked out in contrast to the new, innovative design AMG/MAN bus.

## TABLE 4.5

### Repair Frequency and Average Labor Hours Expended According to Maintenance Category[1]

### Observation Period: November 1, 1979 through June 30, 1980

| VMS Category Code | Category Label | GM - 1976 Number of Repairs | GM - 1976 Average Labor Hours | AMG/MAN - 1979 Number of Repairs | AMG/MAN - 1979 Average Labor Hours |
|---|---|---|---|---|---|
| PM | Preventative Maintenance | 560 | 3.0 | 864 | 3.3 |
| 11 | A/C and Heat | 47 | 2.3 | 270 | 3.8 |
| 12 | Air System | 28 | 2.4 | 145 | 2.7 |
| 13 | Brakes | 35 | 1.1 | 11 | 1.7 |
| 14 | Bus Exterior | 98 | 1.7 | 98 | 2.0 |
| 15 | Bus Interior | 96 | 0.9 | 139 | 1.5 |
| 16 | Chassis and Suspension | 28 | 2.3 | 32 | 3.7 |
| 17 | Convertor | 69 | 2.2 | 28 | 2.6 |
| 18 | Cooling System | 42 | 1.4 | 35 | 3.7 |
| 19 | Doors | 72 | 1.3 | 39 | 2.7 |
| 20 | Electrical | 43 | 2.1 | 93 | 2.6 |
| 21 | Engine | 24 | 3.9 | 35 | 2.4 |
| 22 | Fuel and Exhaust | 26 | 1.9 | 53 | 3.8 |
| 23 | Lights | 78 | 1.1 | 49 | 1.2 |
| 24 | Lubrication | 9 | 1.1 | 26 | 1.9 |
| 25 | Signs | 3 | 0.9 | 50 | 1.3 |
| 26 | Steering | 0 | 0.0 | 1 | 13.4 |
| 27 | Tires and Wheels | 45 | 1.1 | 78 | 1.5 |
| 31 | Communication | 3 | 1.4 | 6 | 5.4 |
| | All Problems | 1,337 | 2.2 | 2,052 | 2.9 |
| | Thousands of Bus-Miles | 571.3 | | 384.4 | |

Data: Courtesy of Chicago Transit Authority

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[1] Twenty buses of each type were compared, using data for perioa

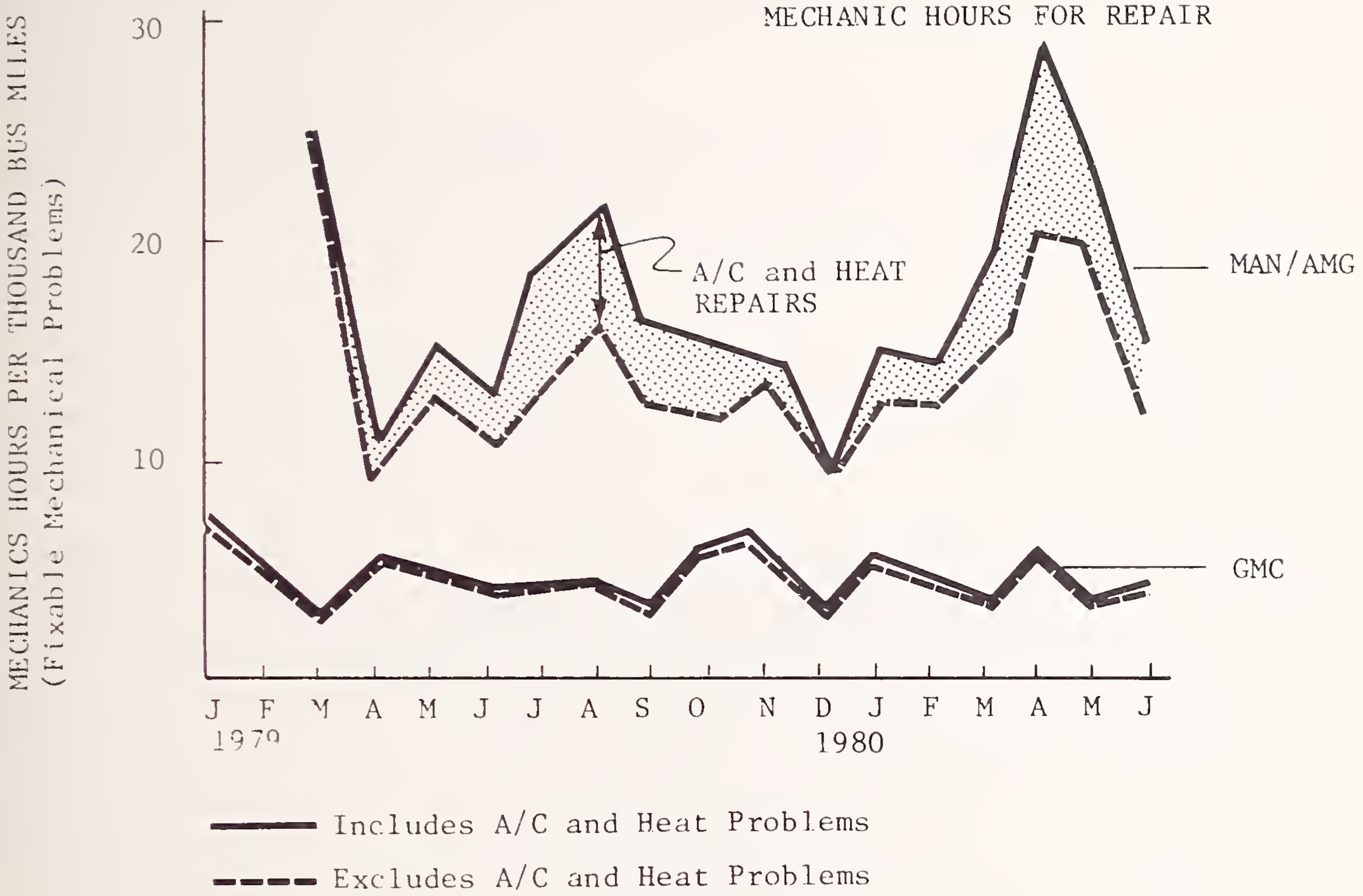


FIGURE 4.2

Chicago Maintenance Experience:
Mechanic Hours for Repairs, by Month

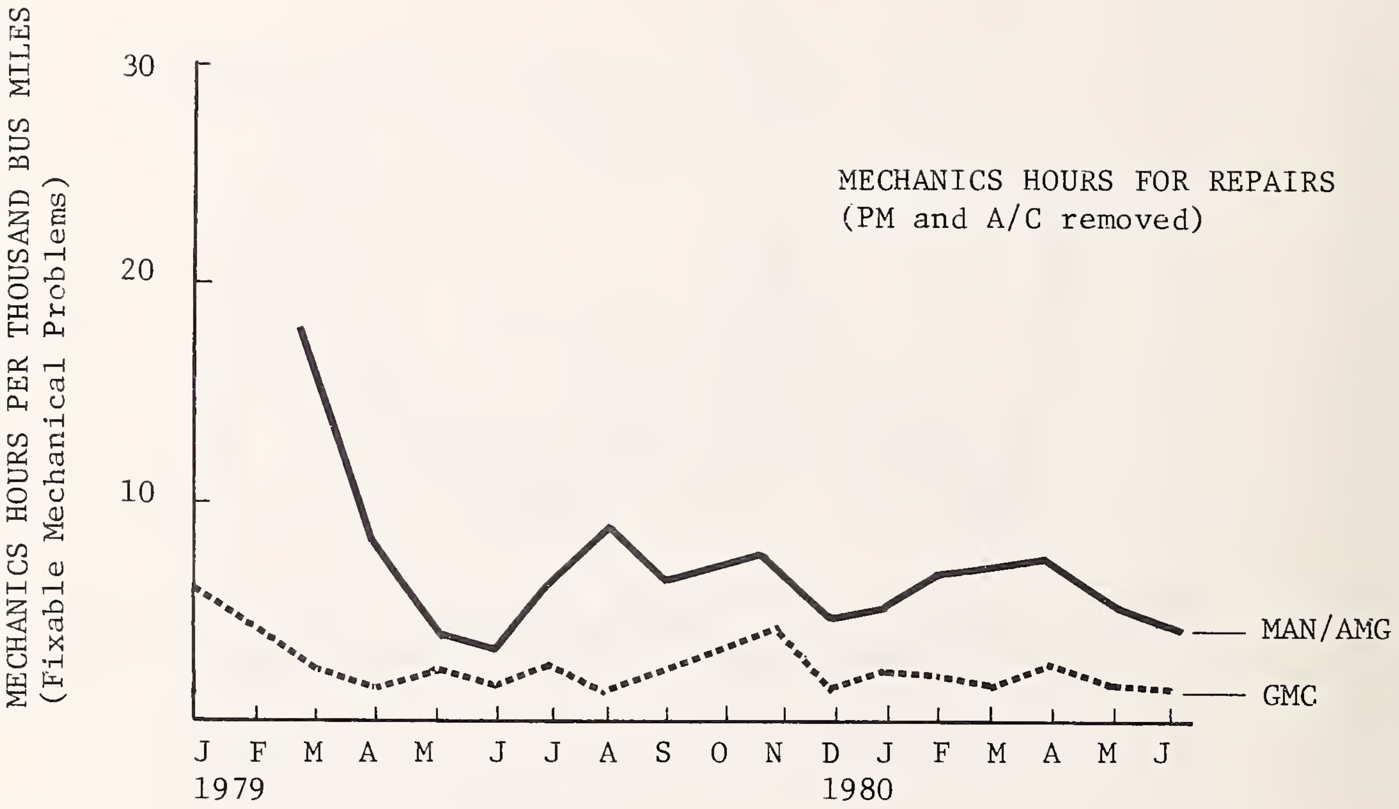


FIGURE 4.3

Chicago Maintenance Experience:
Mechanic Hours for Repairs with Air Conditioning Repairs
and Preventative Maintenance Removed

A comparison of the articulated bus with a newer conventional bus is possible using data provided by the Phoenix Transit System. Phoenix acquired a fleet of 37 GM RTS-II buses at the same time as they acquired their 20 articulated buses. Table 4.6 shows the number of days out of service over an eight-month period immediately following their introduction to service for the 20 articulated buses and for 20 of the RTS-IIs. Overall, the articulated buses had 20 percent more out-of-service days but show a greatly improved record over the last four months. If one normalizes for bus-miles driven per month, however, the articulated buses had 75 percent more days out-of-service per 100,000 bus miles. Still, it must be borne in mind that Phoenix's articulated buses had an inordinate amount of trouble with the air conditioning system, which could account for much of the service outage.

## 4.4 Road Call Experience

In addition to repairs made in the shop, another measure of a vehicle's reliability is its road call experience. An analysis of road call experience is especially important for two reasons: (1) road calls are expensive because they waste driver resources as well as mechanic hours, and (2) road calls directly affect the riding public and produce highly negative and longlasting impressions of a transit operation.

Figures 4.4 and 4.5 illustrate the experience of two operators, Phoenix and Chicago. To account for differences in vehicle mileage, monthly road calls per 10,000 miles were plotted. Pittsburgh mileage data was unavailable, so no comparable plot was possible.

Each property defines "road call" somewhat differently. For example, Phoenix only includes road calls lasting more than five minutes; Chicago counts road calls only for vehicles in revenue operation, and then only if they are unable to continue in revenue service. Nevertheless, the data appears to tell a consistent story. The frequency of road calls fluctuates from month to month, but the articulated bus averages 4.4 road calls per 10,000 miles in Chicago compared to 2.9 for the GM standard bus (52 percent more). In Phoenix, the articulated bus averages 3.4 road calls per 10,000 miles compared to 1.5 for the GM RTS-II buses, more than twice as many.

Interestingly, comparable data from Seattle shows more favorable road call experience with the articulated buses than with their 1976 AMG conventional buses. Figure 4.6 illustrates "trouble call" frequency for both vehicle types per 10,000 miles over a five-month period for which these data were available. A "trouble call" refers to a breakdown or other problem which requires a coach change. A "chargeable" trouble call is a breakdown due to a mechanical failure; a "non-chargeable" trouble call is one not considered the fault of maintenance, e.g., vandalism, tire failure, radio failure, accident or unsanitary coach.

Over this five-month period, the 214 older AMG conventional buses averaged a consistent 4.6 trouble calls per 10,000 miles, whereas the 150 AMG/MAN articulated buses averaged only 2.7 trouble calls per 10,000 miles, some 41 percent fewer. Part of this better record with articulated bus in Seattle is undoubtedly due to the greater familiarity of both mechanics and

TABLE 4.6

Monthly Vehicle Availability in Phoenix for 20 New AMG/MAN Articulated Buses and 20 New RTS-II Buses

| | Days Out of Service | |
|---|---|---|
| Month | RTS-II | AMG/MAN |
| September 1979 | 68 | 94 |
| October 1979 | 107 | 109 |
| November 1979 | 18 | 73 |
| December 1979 | 42 | 79 |
| January 1980 | 48 | 60 |
| February 1980 | 39 | 20 |
| March 1980 | 35 | 10 |
| April 1980 | 15 | 7 |
| | 372 | 445 |
| Average Bus-Miles Per Month | 66,859 | 45,673 |
| Days Out-of-Service Per 100,000 Miles | 69.5 | 121.8 |

Data: Courtesy Phoenix Transit System

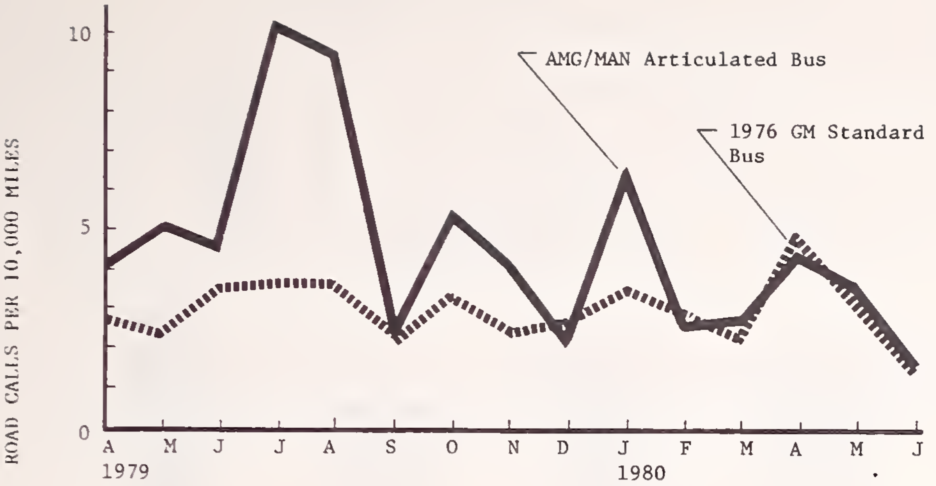


FIGURE 4.4

Road Calls per 10,000 Miles--Chicago Experience

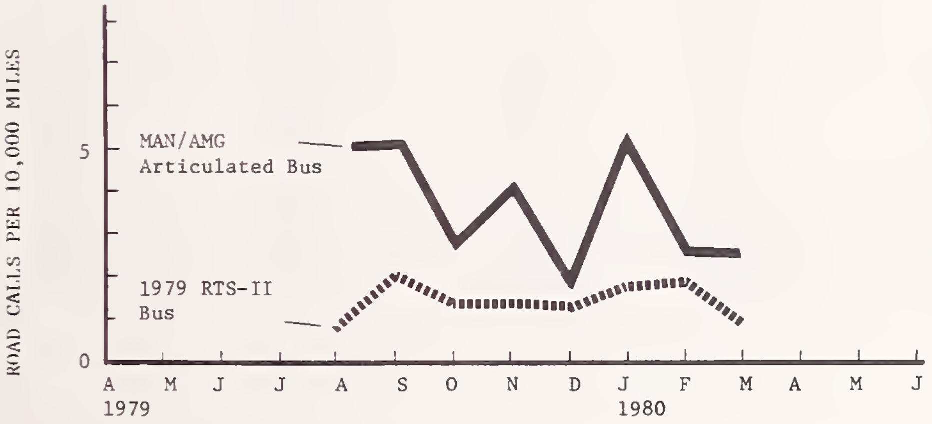


FIGURE 4.5

Road Calls per 10,000 Miles--Phoenix Experience

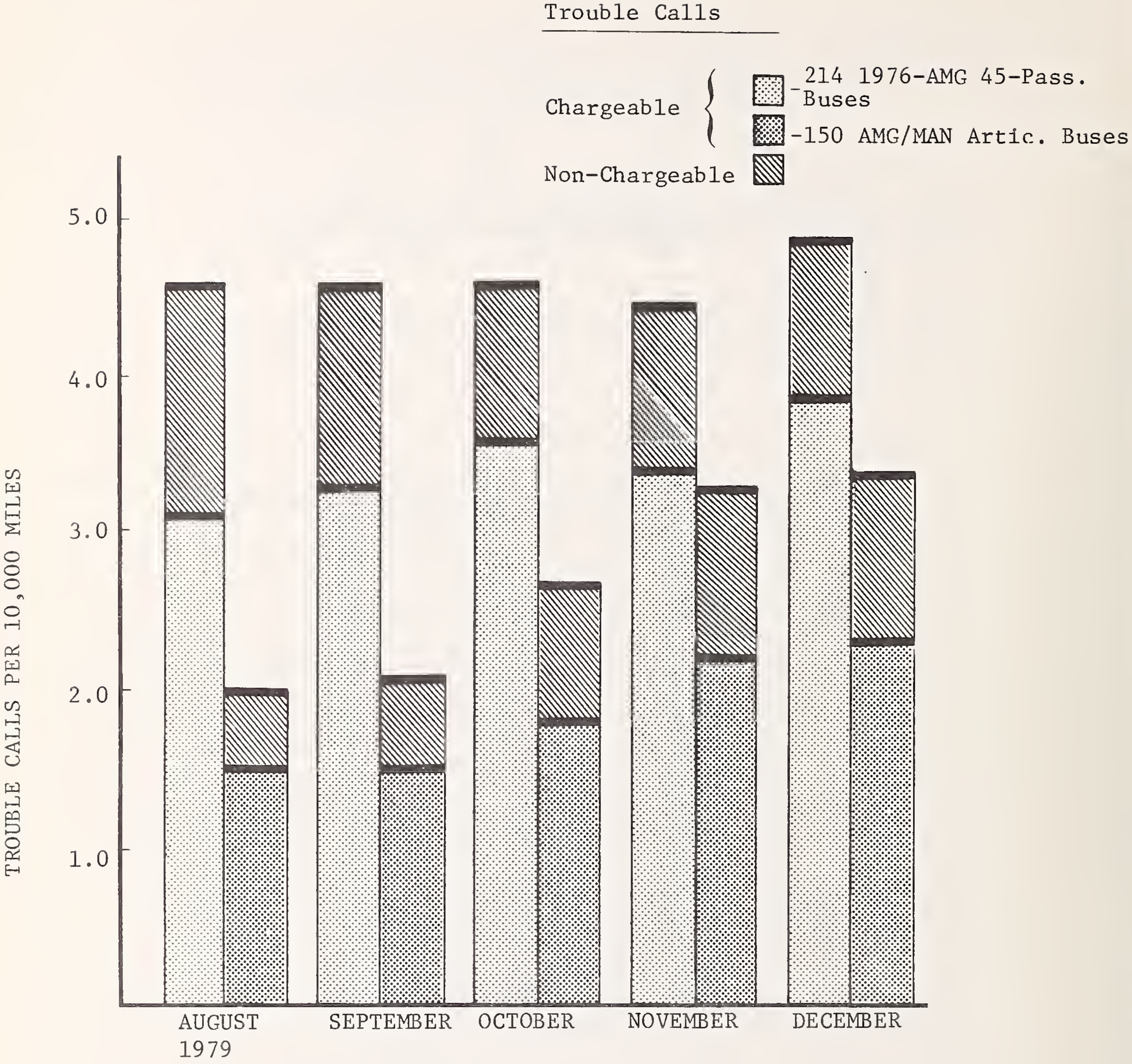


FIGURE 4.6

Monthly Trouble Calls per 10,000 Miles -- Seattle Metro drivers with the articulated bus because of the much larger articulated fleet size. However, another significant factor in Seattle's better road call record is the absence of air conditioners in its articulated bus fleet; air conditioning failures, as noted previously, are a major cause of articulated bus breakdowns. Thus, the lower trouble call rate for the articulated bus in Seattle is perhaps explainable; what is less explainable is why the AMG conventional buses have such a high rate. Also, we should not overlook the fact that only five months experience is available for this comparison. Nor should we fail to observe that both sets of buses had an increasing trouble call rate for the period but that the articulated buses increased at faster rate (relatively and absolutely).

The average number of road calls per 10,000 miles is summarized below for quick reference. One must keep in mind, however, that the different properties have different definitions of road calls plus different conventional buses to compare the articulated buses against.

No. Road Calls per 10,000 Miles

|  | Articulated Bus | Conventional Bus | Ratio Articulated: Conventional |
|---|---|---|---|
| Chicago | 4.4 | 2.9 (1976 GM) | 1.52 |
| Phoenix | 3.4 | 1.5 (1979 GM RTS-II) | 2.27 |
| Seattle | 2.7 | 4.6 (1976 AMG) | 0.59 |

## 4.5 False Alarms

Another interesting finding in the maintenance data for Chicago is the relative frequency of "checked and OK" maintenance. This occurs when a problem with a bus is reported to maintenance, and, after investigation, no problem can be found. Data on this occurrence is shown in Table 4.7. These figures for "checked and OK" maintenance are not included in the shop repair figures, i.e., these false alarms are over and above the repairs in the repair records analyzed earlier.

Although the 20 articulated buses logged only about 56 percent as many miles per month as the conventional buses, they averaged nine times more mechanic hours spent for "checked and OK" maintenance (1568 hours versus 173 hours or 87.1 hours per month versus 9.6 hours per month) than did the same number of conventional buses. Moreover, the mechanic hours spent on "checked and OK" maintenance is not insignificant--typically 15 percent of the actual shop repair hours logged per month.

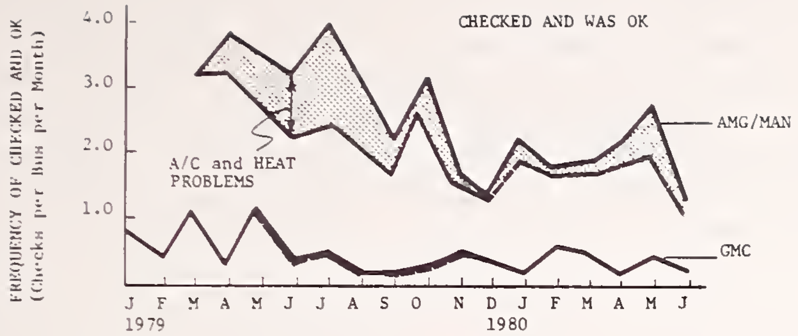
The data from Table 4.7 are presented graphically in Figures 4.7 and 4.8. Figure 4.7 shows that the articulated bus is much more likely to be unnecessarily flagged for service by a driver than is the older GM conventional bus. A significant portion of the "false alarms" can be attributed to perceived air conditioning problems. Figure 4.8 adjusts this data for mileage driven, which merely accentuates the difference between the two buses.

TABLE 4.7

### Monthly Summary of Repair Requirement and Related Items For 20 GM Buses (1976) and 20 AMG/MAN Buses (1979) Chicago, Illinois

| | Shop Repairs | | | | Checked and OK | | | | Thousands of Bus-Miles | |
|---|---|---|---|---|---|---|---|---|---|---|
| | GM | | MAN/AMG | | GM | | MAN/AMG | | | |
| Month | No. | Avg. Lbr. Hrs. | No. | Avg. Lbr. Hrs. | No. | Avg. Lbr. Hrs. | No. | Avg. Lbr. Hrs. | GMC | MAN/AMG |
| 1/79 | 178 | 2.3 | 1 | 7.2 | 17 | 1.2 | 0 | 0.0 | 50.1 | N/A |
| 2/79 | 165 | 2.1 | 16 | 3.0 | 9 | 0.9 | 5 | 1.1 | 57.3 | N/A |
| 3/79 | 162 | 1.9 | 244 | 1.9 | 21 | 1.5 | 66 | 1.2 | 79.9 | 18.7 |
| 4/79 | 165 | 2.4 | 238 | 2.3 | 8 | 0.7 | 77 | 1.5 | 65.6 | 51.4 |
| 5/79 | 173 | 2.0 | 258 | 2.7 | 24 | 0.7 | 70 | 1.1 | 63.8 | 46.2 |
| 6/79 | 167 | 2.0 | 219 | 3.0 | 8 | 0.5 | 63 | 1.2 | 73.9 | 47.4 |
| 7/79 | 143 | 1.9 | 256 | 2.6 | 9 | 0.9 | 80 | 1.5 | 63.3 | 34.6 |
| 8/79 | 128 | 2.1 | 307 | 2.8 | 6 | 0.5 | 62 | 2.0 | 64.1 | 39.2 |
| 9/79 | 128 | 2.4 | 277 | 2.9 | 5 | 0.6 | 42 | 2.3 | 73.3 | 50.0 |
| 10/79 | 169 | 2.6 | 230 | 3.1 | 8 | 0.6 | 62 | 1.7 | 66.4 | 46.5 |
| 11/79 | 172 | 2.8 | 181 | 3.4 | 10 | 3.4 | 32 | 2.4 | 65.7 | 43.7 |
| 12/79 | 116 | 2.0 | 139 | 3.0 | 7 | 0.9 | 27 | 2.0 | 74.3 | 44.5 |
| 1/80 | 151 | 2.6 | 192 | 3.2 | 4 | 1.6 | 43 | 1.9 | 62.2 | 41.6 |
| 2/80 | 150 | 2.4 | 199 | 2.8 | 11 | 0.9 | 36 | 3.0 | 63.6 | 38.8 |
| 3/80 | 150 | 2.3 | 255 | 3.4 | 10 | 0.6 | 37 | 3.1 | 85.3 | 47.9 |
| 4/80 | 189 | 2.3 | 319 | 3.4 | 5 | 2.0 | 42 | 2.7 | 67.0 | 36.3 |
| 5/80 | 151 | 1.8 | 284 | 3.3 | 6 | 0.5 | 55 | 3.3 | 68.7 | 38.0 |
| 6/80 | 174 | 2.1 | 255 | 3.2 | 5 | 0.6 | 26 | 3.0 | 84.5 | 57.6 |
| TOTAL | 2831 | 2.2 | 3870 | 2.9 | 173 | 1.0 | 825 | 1.9 | 1228.9 | 682.4 |
| TOTAL HRS. | 6228 | | 11,223 | | 173 | | 1568 | | | |
| AVG. HRS./ 1,000 MILES | 5.1 | | 16.4 | | 0.1 | | 2.3 | | | |

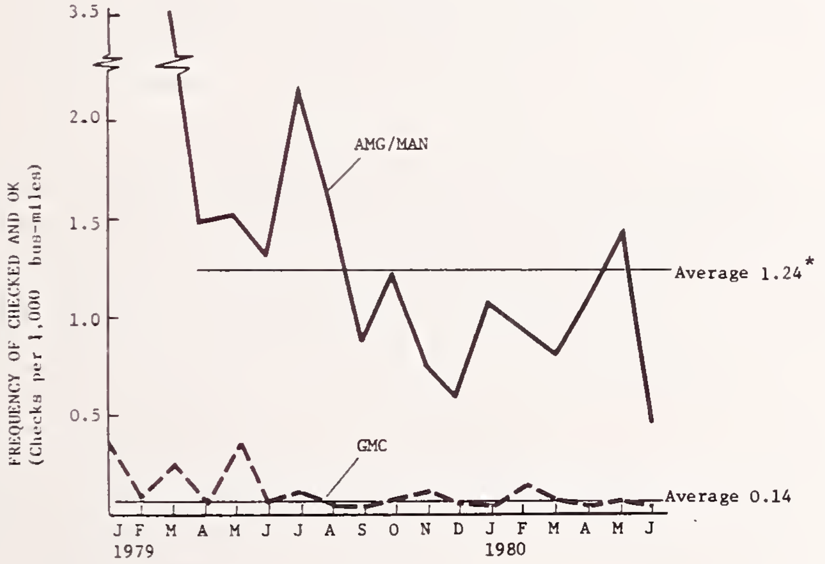
Data: Courtesy of Chicago Transit Authority



Source: Chicago Transit Authority

FIGURE 4.7

Frequency of "Checked and OK" per Bus per Month



*Excludes January through March

Source: Chicago Transit Authority

FIGURE 4.8

Frequency of "Checked and OK" per Thousand Bus-Miles

Three reasons could account for this wide disparity; two are related to Chicago's policy of rotating articulated buses to different routes each day. First, it is very likely that because of this policy, the driver has not driven an articulated bus for some time and is not familiar enough with the bus to recognize the difference between true problems and simple differences in the way in which the articulated bus handles or performs. A second cause may stem from driver insecurity. Drivers who are not practiced with the articulated bus may be unsure of their ability to handle it, and, because by union rules a driver is not required to drive any bus in need of repair, he may call a false alarm for service simply to avoid having to drive the bus at all. A third factor which also contributes to the higher number of labor hours expended on articulated buses is the unfamiliarity of maintenance personnel with the buses. As stated earlier, this unfamiliarity could result from the newness of the vehicle or from the relatively small proportion of Chicago's fleet at any one garage which limits a repairman's exposure to the bus. For whatever reason, CTA repairmen currently average 1.9 labor hours to troubleshoot an articulated bus, but only 1.0 labor hours for the older GM bus.

It is also clear from the graph that in the early stages of usage of the articulated bus, either the drivers were more suspicious of the bus or mechanics didn't know how to translate suspected problems into identifiable problems, or both.

## 4.6 Conclusions

Overall, the following conclusion may be drawn on maintenance. Initial data show that the AMG/MAN articulated bus requires maintenance at least twice as frequently as does the GM bus. Even a healthy preventative maintenance program leaves a residual requirement for mechanics' labor which is almost three times as great as that required for the conventional buses. However, mechanics and drivers alike are still just becoming acquainted with the articulated bus, and a significant part of the mechanic hours incurred can be attributed to false alarms and lack of familiarity with the articulated bus. Chicago's policy of random deployment probably leads to a high number of "checked and found OK" problems on the articulated bus due to driver unfamiliarity. Frequency of road calls is greater for articulated buses by a factor of 52 percent in Chicago and 127 percent in Phoenix, although the conventional buses have a road call frequency 70 percent greater than the articulated buses in Seattle. More definitive conclusions on articulated bus maintenance must await further experience with the bus.

# 5. COST ANALYSIS

The greater passenger-carrying capacity of articulated buses makes it possible for them to transport a given number of people with fewer vehicles than would be required if conventional buses were used. Whether in replacing existing vehicles or in adding vehicles to the fleet, the substitution of some number of articulated buses for a larger number of conventional buses yields a direct savings in driver labor costs. If these labor cost savings exceed the sum of the higher capital and non-labor operating costs usually associated with articulated bus utilization, then cost savings accrue.[1] These cost savings (or increases) then must be carefully weighed against any losses (or gains) in level of service benefits enjoyed by passengers relative to those which would be associated with the alternative conventional bus deployments.

The cost analysis presented in this section compares the costs of articulated bus purchase and operations with those of conventional buses. As is reflected in the discussion above, the choice between these vehicles is open to operators regardless of whether or not they wish to increase or decrease the size of their fleets or volume of service provided to consumers. Thus our analysis examines articulated bus deployments which range from increasing the volume of service provided to decreasing it.

Each of these articulated bus deployments necessarily impacts the characteristics of service provided to existing and potential transit riders. For example, if articulated buses are substituted at some fractional ratio for conventional buses, there are likely to be increases in in-vehicle travel times and in passenger wait time. In the next chapter, the level of service impacts on passengers resulting from the use of the articulated buses are identified and quantified, and the benefits and costs of selected articulated bus deployments examined.

This chapter, which presents the cost analysis, has two parts. Section 5.1 discusses the general approach used in modeling the cost components and estimating the costs that must be considered. The results of the empirical analysis performed are presented in Section 5.2. A more detailed discussion of the modeling and cost estimation procedures used in the analysis can be found in Appendix B.

## 5.1 Approach

The goal of the analysis is to ascertain the capital plus operating costs of articulated bus deployment. This entails calculating the costs of purchasing and operating a given number, A, of articulated buses instead of

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[1] While on a per vehicle basis, both annualized capital costs and non-labor operating costs are higher for an articulated bus, the substitution of a given number of articulated buses for a larger number of conventional buses may result in total capital costs or non-labor operating costs which are lower for the articulated buses than for the conventional buses which they replace.

some number, B, of conventional buses, where A-for-B is the articulated bus substitution rate (e.g., 2-for-3, 3-for-4). One simple approach would be to calculate the sum of the annual operating costs plus the amortized capital costs for B conventional buses and for A articulated buses, and subtract the latter from the former to give the cost savings (or increases) resulting from articulated bus purchase and operation. However, this simple approach will yield misleading results because of the expectation that articulated buses will be operated fewer miles per year than the average conventional bus. Since efficient articulated bus utilization will typically occur at times of high passenger loading (generally in the peak period only), and since conventional buses have lower per mile operating costs than articulated buses, greater operating cost savings are gained by limiting articulated bus operation to these periods of high passenger loading. The much lower yearly mileage that articulated buses consequently experience when deployed in this manner also results in longer articulated bus life and shorter conventional bus life, since the average annual utilization of the remaining conventional buses in the fleet must rise.

To incorporate these effects in the cost analysis, it is necessary to use a life cycle cost approach in which two alternative investments are considered and compared. The first is the base case in which there is an investment in an all-conventional bus fleet. The second case entails an investment in articulated buses which results in a mixed articulated and conventional bus fleet. In the base case, an existing all-conventional bus fleet is assumed to continue in operation for a specified number of years. Over that time span, these buses, as they reach the end of their useful lives, are replaced on a one-for-one basis with new conventional buses. In the articulated bus case, in which the fleet is initially the same as in the base case, the transit operator purchases A articulated buses in place of B conventional buses. It is assumed that the A articulated buses purchased replace the first B conventional buses that reach the end of their useful lives and that the resulting mixed articulated and conventional bus fleet is in operation for the same number of years as the all-conventional bus fleet in the base case. During this period, as the conventional and articulated buses reach the end of their useful lives, they are replaced on a one-for-one basis with new buses of the same type.

To estimate the costs of each alternative investment, the present value of its costs (PVC) is computed, where the present value is equal to the total of all present and future costs discounted by the opportunity cost of money. Theories of capital budgeting suggest that the present value approach is a most effective one to use when life cycle costs and alternative uses of money are being considered. This approach has been particularly emphasized for governmental decision-making and is endorsed by Office of Management and Budget (OMB).[2] In calculating present value, a real, uninflated discount rate of 10%, suggested by OMB in their economic feasibility evaluation guidelines,

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[2] Dooley, T., and J. Putukian, "Articulated Bus Investment Analysis," draft study, Transportation Systems Center, Cambridge, MA, January 1977.

is used.[3] By assuming that all cost components used in the analysis will be subjected to the same inflation rate, all costs can be represented in 1980 constant dollars.

A 30 year time span is selected in order to capture accurately the life cycle capital costs that result from the deployment of articulated buses in many of the scenarios being examined in the study and compare those costs with the life cycle capital costs resulting from the deployment of conventional buses in the base case scenario. Initially, both conventional and articulated buses are assumed in the analysis to have 15 year lives when operated the same number of miles as an average bus in an all-conventional bus fleet. However, the much lower yearly mileage that articulated buses would operate under many of the scenarios examined is assumed to lengthen articulated bus life substantially. The lengthened articulated bus life leads to the use of a 30 year time span rather than a 15 year one.

A PVC can be computed for any articulated bus investment strategy by calculating costs for each of the 30 years, finding the present value of each of the 30 years of costs, and summing all the yearly values. Subtracting this value from the PVC for the all-conventional bus base case gives the PVC that can be attributed to the use of the articulated buses. If this value is positive for a given articulated bus investment strategy, then that investment strategy produces a cost savings.

Four different substitution rates are examined:

- 1-for-1,
- 3-for-4,
- 2-for-3, and
- 1-for-2.

These substitution rates cover the range of those which a transit operator might consider. For each substitution rate, three different deployment scenarios are analyzed:

- peak period only deployment of articulated buses on express routes,
- peak period only deployment on local routes, and
- all day deployment on local routes (excluding very early morning, evening, and weekend services).

These scenarios and combinations of these scenarios reflect a range of deployment options operators might consider.

For analysis purposes, the annual cost of any investment strategy is divided into three components: capital costs, non-driver operating costs, and driver operating costs. Based on purchase prices for 1980 delivery, a 60-foot articulated bus with air conditioning has a capital cost in the range of $235,000-$260,000. Fifty-five-foot buses cost about 3-5% less. Two recently

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[3] Office of Management and Budget Circular No. A-94 (Revised), Washington, DC, March 27, 1971.

available conventional buses, the GM RTS-II and the Grumman 870, both air conditioned, cost approximately $130,000 in 1980.[4] The relative purchase prices of articulated and conventional buses will vary with order size and accessories desired, and many factors will determine the relative prices of the two buses in the future. Because of the possible range in the relative prices of the two buses and the sensitivity of the results to these relative prices, the articulated bus capital cost is represented in the analysis as a multiple, C, of the 1980 conventional bus capital cost, or $130,000C. In examining the results of the cost analysis, a range of values is used for this multiplier. The cost of special hoists needed to service the articulated buses is an added capital cost which is included in the articulated bus case. Because existing operational experience at U.S. properties gives little indication of the circumstances under which additional garaging facilities will be needed for articulated buses and how these facilities will impact the need for replacement of existing conventional bus garaging facilities, fixed facility capital costs are assumed to be identical for all investment strategies. In reality, these costs may be higher for the articulated bus strategies.

Non-driver operating costs (i.e., vehicle maintenance, fuel, and insurance) can be compared in terms of average annual costs given the same number of miles of operation for both bus types. Overhead costs are assumed to be the same for all investment strategies. APTA 1980 operating statistics for a sample of U.S. transit properties having more than 400 buses in their fleets indicate the following average annual non-driver operating costs per conventional bus:[5]

| | | |
|---|---|---|
| maintenance (including labor) | = | $14,000 |
| fuel | = | 10,000 |
| insurance | = | 4,000 |
| Total | = | $28,000 |

Since most transit properties are self-insured, insurance costs are based upon liability claim costs.

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[4] Capital costs are based on bid price data obtained from MAN and from UMTA's Office of Transit Assistance. Articulated bus capital costs in 1980 are obtained by extrapolation between capital costs for buses delivered in late 1978 and ones scheduled for delivery in 1982.

[5] (1) American Public Transit Association, "Transit Labor Expense Components for Transit Systems with Fiscal Years Ending in January, February, March, April, May, and June 1980," Washington, DC, February 2, 1981.
(2) American Public Transit Association, "Comparative Labor Practices; Report No. 2: Number of Vehicles by Type (as of October 1, 1980)," Washington, DC, January 2, 1981.
(3) Data on fuel usage and costs at selected transit properties supplied in telephone conversations with American Public Transit Association during April 1981.

Operating cost data for the articulated bus are derived by comparative analysis with conventional buses. These operating costs are assumed to be the same for 55- and 60-foot buses for the following reasons:

(1) With the mechanical components of the two buses basically the same, differences in these costs between the two buses are due only to the differences in weight and length and to the one extra set of rear doors on some 60 foot buses. These differences are felt to be small both in absolute terms and in comparison to the range of estimated maintenance costs.

(2) There are no data available for this analysis to indicate any large differences between these costs for the two buses.

The range of articulated bus maintenance costs is taken to be 1.5 to 2 times the maintenance costs of conventional buses based on the findings of Chapter 4. Fuel costs for articulated buses are estimated to be 10% higher than for conventional buses on the basis of an average 10% higher fuel consumption indicated in data from five cities (see Table 5.1). However, the rather small differences in fuel consumption between the two bus types should be viewed with caution since the articulated buses at the five sites tend to be operated on more fuel efficient routes (i.e., more express routes) than the average routes traversed by the conventional bus fleet. Note that in Chicago, where articulated buses are operated on diverse routes, the fuel consumption figures are 15% higher for articulated buses. Insurance costs reflect the higher accident rate for articulated buses, which is twice that of conventional coaches as reported in Chapter 4.

Thus, an articulated bus, if operated the same number of miles as an average conventional bus, is estimated to have the following non-driver operating costs per vehicle:

maintenance (including labor) = \$21,000 to 28,000
fuel = 11,000
insurance = 8,000
Total = \$40,000 to 47,000

Articulated buses normally would be operated considerably fewer miles per year than conventional buses, on average. Since efficient articulated bus utilization typically will occur at times of high passenger loading (generally in the peak period only), and since conventional buses have a lower per mile operating cost than articulated buses, operating cost savings may be gained by limiting articulated bus operation to these periods of high passenger demand.

Actual annual non-driver operating costs per articulated bus calculated in the analysis are directly proportional to the mileage articulated buses accumulate relative to the average accumulated by conventional buses in an all-conventional bus fleet. Depending upon the manner in which they are utilized, it is estimated that articulated buses will accumulate mileage at between 40 percent and 75 percent of the conventional bus rate. Specifically, for the three deployment scenarios examined in the analysis, the following mileage accumulation rates are assumed:

TABLE 5.1

## A Comparison of Fuel Economy By Bus Type

| | Miles per Gallon | | Ratio of Artic MPG to Standard MPG |
|---|---|---|---|
| | Artic | Standard | |
| PHOENIX<br>11/79-3/80 | 3.11 | 3.44[1] | .90 |
| SEATTLE<br>1/80-4/80 | 3.62 | 3.97[2] | .91 |
| MINNEAPOLIS<br>1/79-11/79 | 3.42 | 3.78 | .90 |
| PITTSBURGH<br>7/79-3/80 | 2.76 | N.A. | N.A. |
| CHICAGO<br>1/79-12/79 | 2.66 | 3.12[3] | .85 |

[1] 1979 GM RTS-II

[2] 1979 Flyer

[3] 1976 GM (estimated from fuel cost data)

peak period express service - 40%
peak period local service - 60%
all day local service - 75%

The much lower yearly mileage that articulated buses are estimated to experience also results in a somewhat higher yearly mileage of operation for the remaining conventional buses in the fleet, which is reflected in the analysis by adjusting upward the annual non-driver operating costs for the conventional buses.

The much lower yearly articulated bus mileage and somewhat higher conventional bus mileage also results in longer articulated bus life and shorter conventional bus life. The different bus lifespans are reflected in the life cycle capital cost calculations for each investment scenario.

Driver labor costs, unlike capital costs and non-driver operating costs, are not calculated separately for the articulated bus investment scenarios and for the base case all-conventional bus scenario. Rather, annual driver operating cost savings attributable to a particular articulated bus investment strategy are calculated directly. These cost savings accrue directly from the elimination of in-service conventional buses resulting from the substitution of articulated buses in some fractional ratio. APTA statistics on average hourly driver wage rates and on costs for fringe benefits and premium pay are used to calculate the driver operating cost savings resulting from the elimination of each in-service bus.[6]

For each in-service conventional bus eliminated in the peak period only, it is estimated that between $31,600 and $38,600 in driver labor costs per year are saved based on low end and high end estimates of hourly driver wage rates of $9 and $11, respectively. These estimates assume that the elimination of each bus saves annually the driver labor costs associated with working one split shift assignment (composed of a morning and afternoon piece of work) on each of the approximately 250 weekdays in a year. For each in-service conventional bus eliminated during the entire day (weekdays only), it is estimated that between $42,600 and $52,000 in driver labor costs per year are saved based on the $9 and $11 hourly driver wage rates. These estimates assume that the elimination of each bus saves annually the driver labor costs associated with working one straight 8 hour driver assignment and one half of a split shift driver assignment on each weekday in a year.

Total driver labor cost savings resulting from the implementation of any articulated bus replacement strategy are calculated by determining the number of in-service conventional buses that are eliminated and multiplying that number by the annual driver labor cost savings per in-service bus eliminated.

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[6] (1) American Public Transit Association, "Top Hourly Wage Rate Summary -- Part I," Washington, DC, rates reported through March 23, 1981.
(2) "Transit Labor Expense Components," op cit.

The articulated bus substitution rate is, of course, the major determinant of the number of in-service buses that are eliminated. The fewer the number of in-service articulated buses substituted for a given number of in-service conventional buses the greater the number of in-service conventional buses eliminated. However, in determining the number of in-service conventional buses that are eliminated, other factors must also be taken into account.

The first is that buses are out of service some percent of the time either for scheduled or non-scheduled maintenance. On the assumption that each conventional bus is out of service 12% of the time, the elimination of a conventional bus actually yields a reduction of only 0.88 in-service buses.

Another factor is that in-service travel times are longer with articulated buses. One-way in-service travel times on articulated buses are estimated to be as much as 7 minutes greater than on conventional buses depending on the passenger load levels and boarding-deboarding patterns. The travel time differential is greatest on local service and least on express service. The higher in-vehicle travel times translate into a need to utilize more vehicles to provide a comparable frequency of service since vehicles cannot be turned around as quickly to make subsequent trips. This reduces the number of in-service conventional buses that can be eliminated with articulated bus implementation and hence cuts into the potential labor savings. The need for more vehicles also results in higher capital expenditures. It is estimated that to compensate for the articulated buses' slower in-service travel times, the number of articulated buses and drivers must be increased as much as 4.5% on local routes and 1.5% on express routes.

One other factor to be considered in assessing the costs of articulated bus utilization is a higher incidence of road calls and maintenance with articulated buses. Detailed bus maintenance and road call data collected in Chicago, as well as less complete data from Phoenix and Seattle suggest that the incidence of in-service vehicle breakdowns and non-scheduled maintenance is at least 50% higher for articulated buses than it is for conventional buses. Without a greater number of articulated buses available, passengers on routes operating articulated buses would encounter more missed trips than they would on routes operating conventional buses. It is estimated that 4% more articulated than conventional buses are needed to insure that the articulated bus' higher incidence of road calls and repairs does not lead to a higher incidence of missed trips. This allowance for more articulated buses clearly increases articulated bus capital costs. Note, however, that it is not a factor in determining the number of in-service conventional buses eliminated since it has no effect on in-service vehicle requirements.

The cost analysis focuses primarily on the cost of articulated bus utilization as viewed from the perspective of the Federal Government or "society". However, the cost of articulated buses to the transit operator cannot be ignored, since it is the operator who decides whether or not to buy these buses. The societal perspective considers all capital and operating costs, since society ultimately bears these costs. The transit operator, on the other hand, can currently be subsidized by the Federal Government for 80% of the capital cost of all buses purchased (UMTA Section 3 and 5 funds) and for up to 50% of its operating <u>deficit</u> (UMTA Section 5 funds). The operating subsidies actually received by the operators have recently been, on average, covering approximately 13% of their operating costs.[7] Transit operators, faced with severe budgetary constraints, obviously will take Federal subsidization into account in selecting the numbers and types of buses to purchase for their fleets. The analysis considers separately the impacts of Federal subsidies by assuming that annual capital costs from the operator's perspective are only 20% of their actual cost to society and that operators pay 87% of annual operating costs. However, no state or local subsidies are taken into account in the analysis.

Throughout the cost analysis, costs are estimated for the 60-foot articulated bus only. Costs for the 55-foot bus are very similar. Specifically, non-driver operating costs are assumed the same for the 55- and 60-foot buses. Driver cost savings per conventional bus eliminated are the same for both sized buses. Capital costs for 55-foot buses are only 3-5% less than those for 60-foot buses, and this difference in capital costs represents an extremely small percentage of the present value of all costs (i.e., capital and operating) for the two bus types. While costs for the two buses are nearly the same, the capacity of the 55-foot bus is about 12% less than that of the 60-foot bus. Consequently, it is felt that the longer articulated bus is to be preferred in most instances. For this reason, the cost analysis assumes that 60-foot buses are utilized in all articulated bus scenarios examined.

This completes the discussion of the general approach taken in the cost analysis. A more detailed description of the modeling and estimation procedures used in the cost analysis is given in Appendix B.

## 5.2 Results

The range of values possible for each of the cost components leads to considerable uncertainty as to the cost savings that may result from the deployment of articulated buses. To help cope with this uncertainty, two estimates of cost savings -- a high estimate and a low estimate -- are produced for each articulated bus investment deployment strategy considered. The high estimate gives the more favorable view of the articulated bus strategy as it assumes a low-end non-driver operating cost of $40,000 per bus and a high-end labor wage of $11.00 per hour. The low estimate gives a less favorable view of the strategy as it assumes non-driver operating costs of $47,000 per bus and a low-end wage rate of $9.00 per hour.

It is expected that the actual value of cost savings at a particular transit property using articulated buses will likely lie between the high and low estimates. Even where it is apparent that a particular variable value

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[7] "Statement of Secretary of Transportation Drew Lewis before the Subcommittee on Housing and Urban Affairs Senate Committee on Banking, Housing and Urban Affairs, Concerning Proposed Mass Transit Legislation," Washington, DC, May 15, 1981.

exceeds the range used in the analysis, values for other variables may likely compensate.

The analysis results are presented on a normalized basis of annual cost savings per 60-foot articulated bus deployed (obtained by amortizing the present value of cost savings over the 30 year time period and dividing by the total number of articulated buses deployed). The results are presented graphically in Figures 5-1 through 5-6, with the annual cost savings per articulated bus (bracketed by the high and low estimates) plotted as a function of C, the ratio of articulated bus to conventional bus capital cost.

Annual cost savings are shown for the four substitution rates: 1-for-2, 2-for-3, 3-for-4, and 1-for-1. A summary version of the results is presented in Table 5-2 with single high and low estimates of annual cost savings calculated for each articulated bus strategy. The high estimate assumes a value for C of 1.8, while the low estimate uses a value of 2.0. These values reflect the 1980 range of 60-foot articulated bus capital costs relative to conventional bus capital costs.

Figures 5-1 and 5-2 show the regions of cost savings for replacement strategies which use articulated buses in express service in the peak period only, with Figure 5-1 showing the societal perspective and Figure 5-2 showing the transit operator's perspective. Similarly, Figures 5-3 and 5-4 show the corresponding regions of cost savings for replacement strategies employing articulated buses in local service in the peak period only. The cost savings regions for strategies employing articulated buses in all day local service are shown in Figures 5-5 and 5-6.

The following observations and conclusions can be drawn from the results:

(1) One-for-two substitution of articulated buses for conventional buses produces substantial cost savings due to both driver labor cost savings and non-driver operating cost savings, with capital expenditures little different from those incurred in the purchase of conventional buses (since approximately half as many articulated buses would be purchased).

(2) At a 2-for-3 substitution rate, cost savings are produced for all scenarios except for the lower estimate of articulated bus deployment in peak period local service from the societal perspective. The cost savings result from driver labor cost savings which more than offset the higher articulated bus capital expenditures.

(3) At a 3-for-4 substitution rate, articulated bus cost savings can be viewed as marginal in all cases.

(4) A 1-for-1 substitution results in sharply higher articulated bus costs due to higher capital and non-labor operating costs without any savings in driver operating costs.

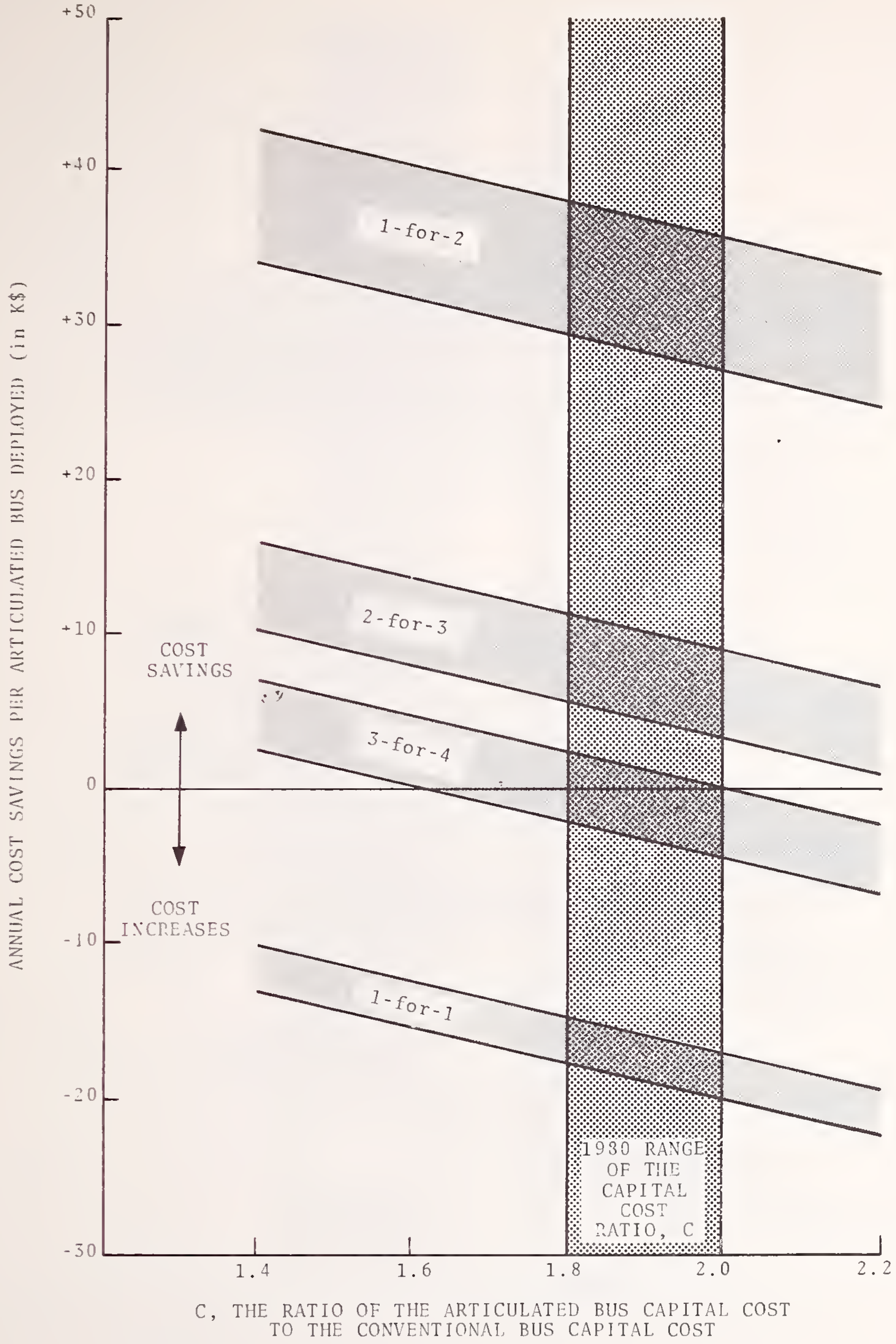

FIGURE 5.1

Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Peak Period Express Service from Society's Perspective

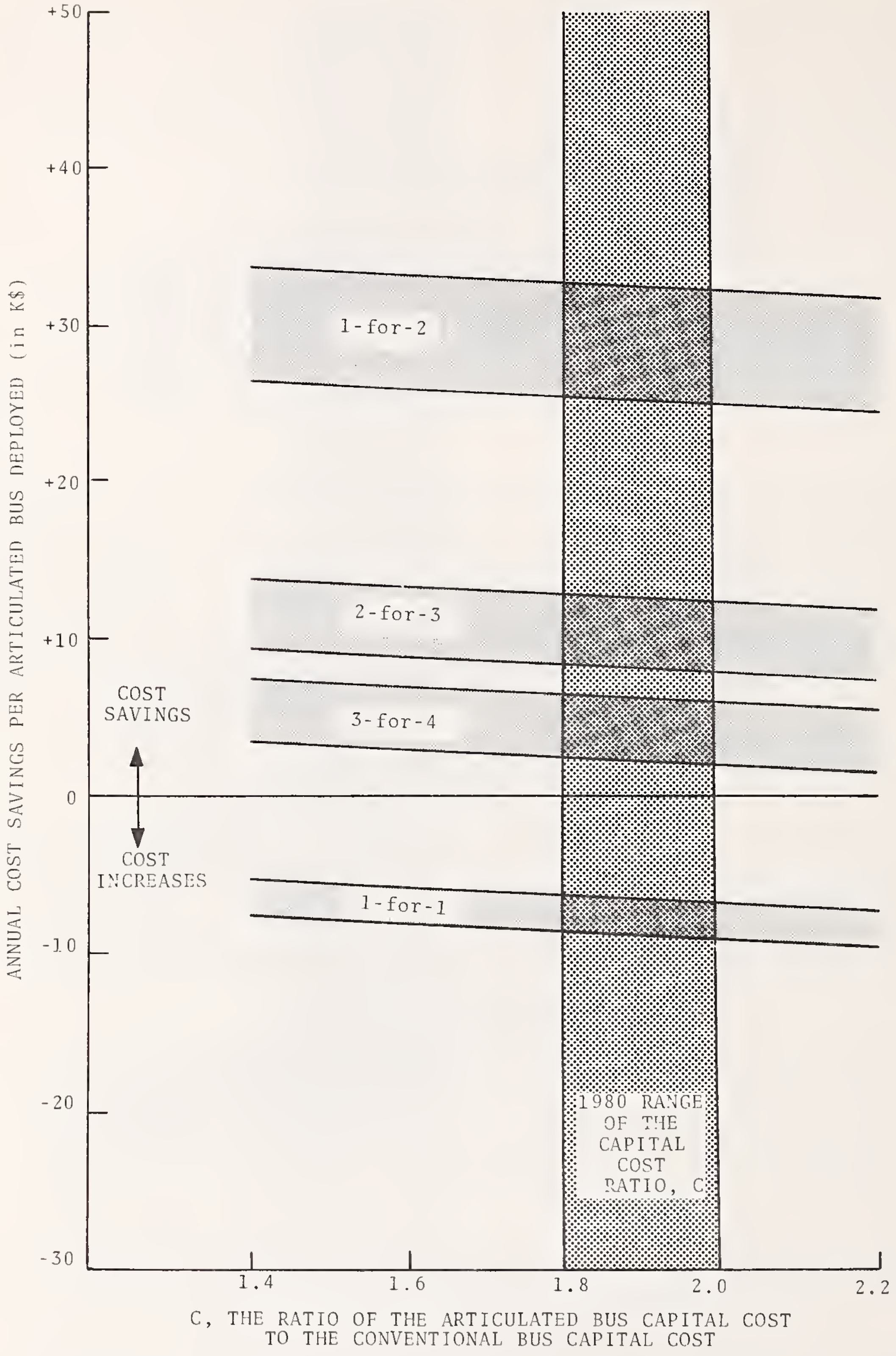

FIGURE 5.2

Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Peak Period Express Service from the Transit Operator's Perspective

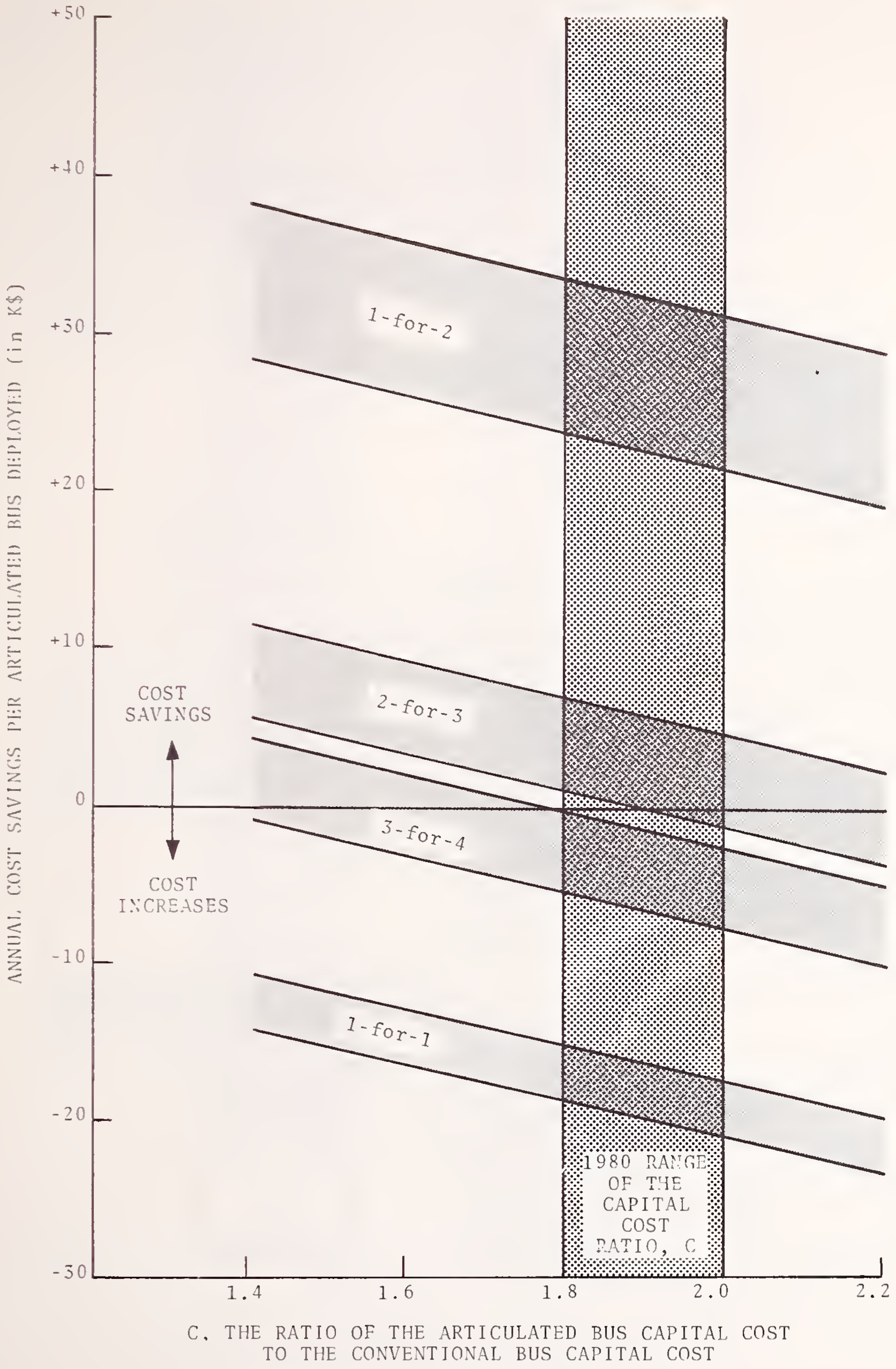

FIGURE 5.3

Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Peak Period Local Service from Society's Perspective

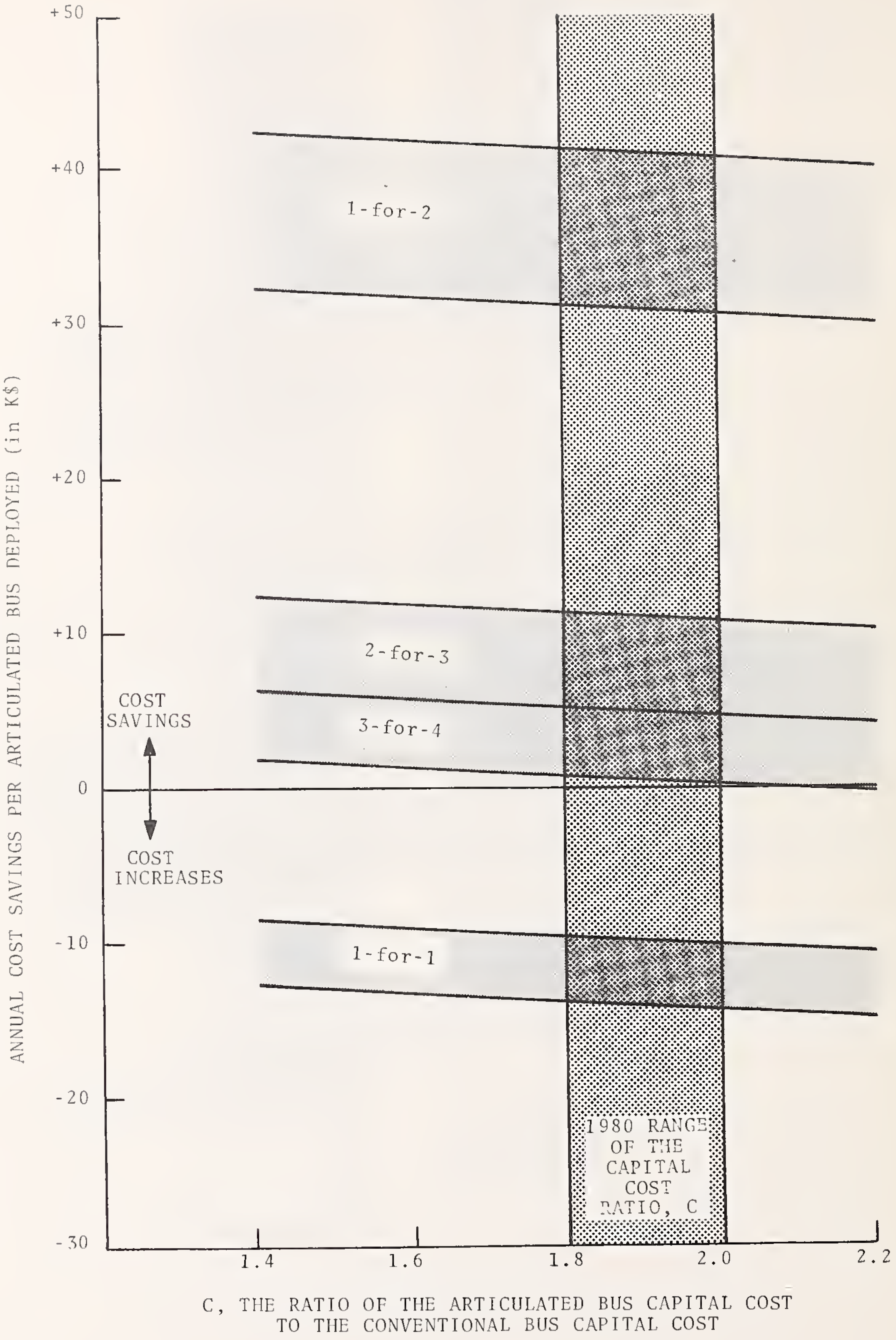

FIGURE 5.4

Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Peak Period Local Service from the Transit Operator's Perspective

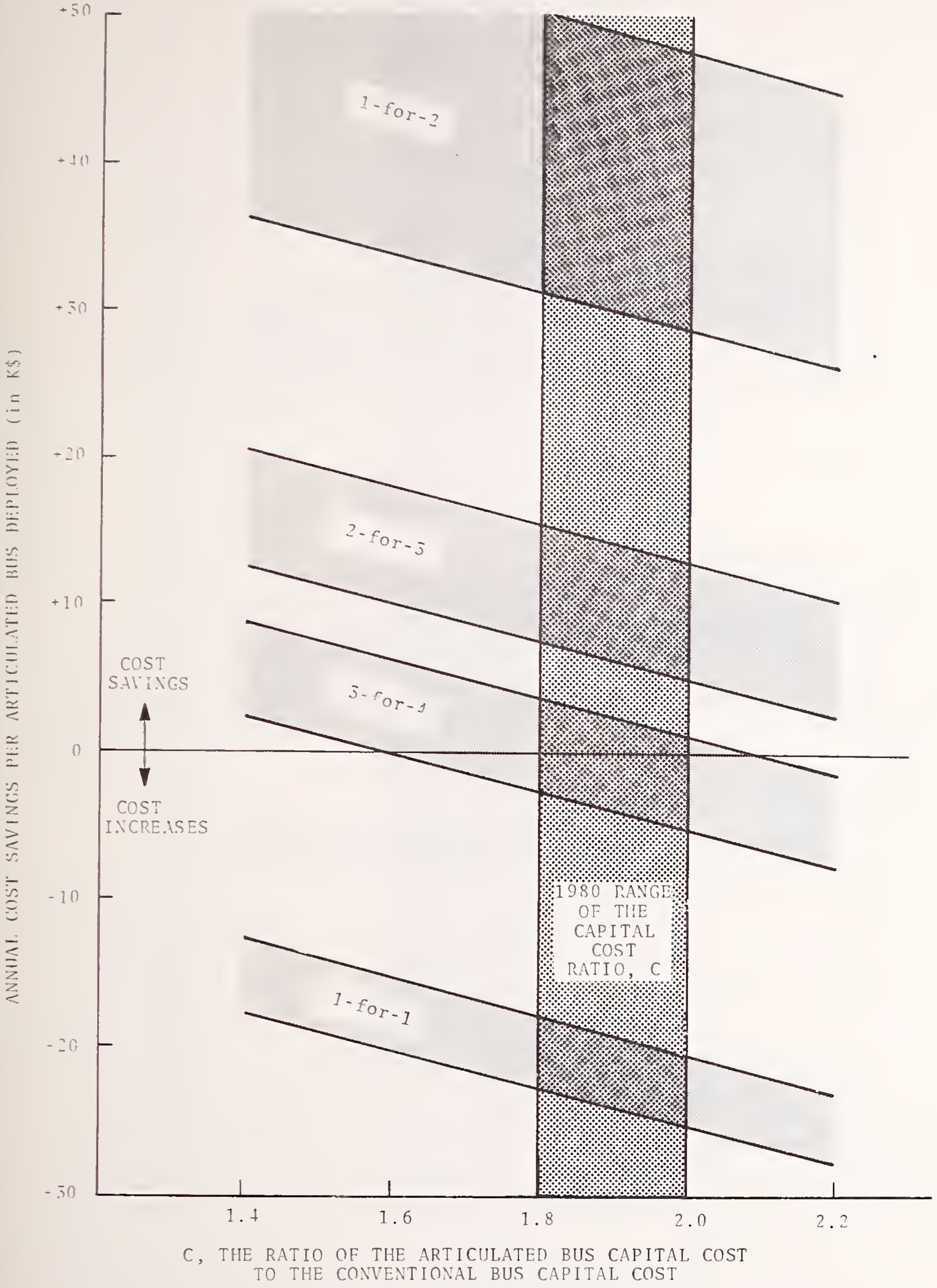

FIGURE 5.5

Annual Cost Savings Resulting From the Substitution of Articulated Buses for Conventional Buses in All Day Local Service from Society's Perspective

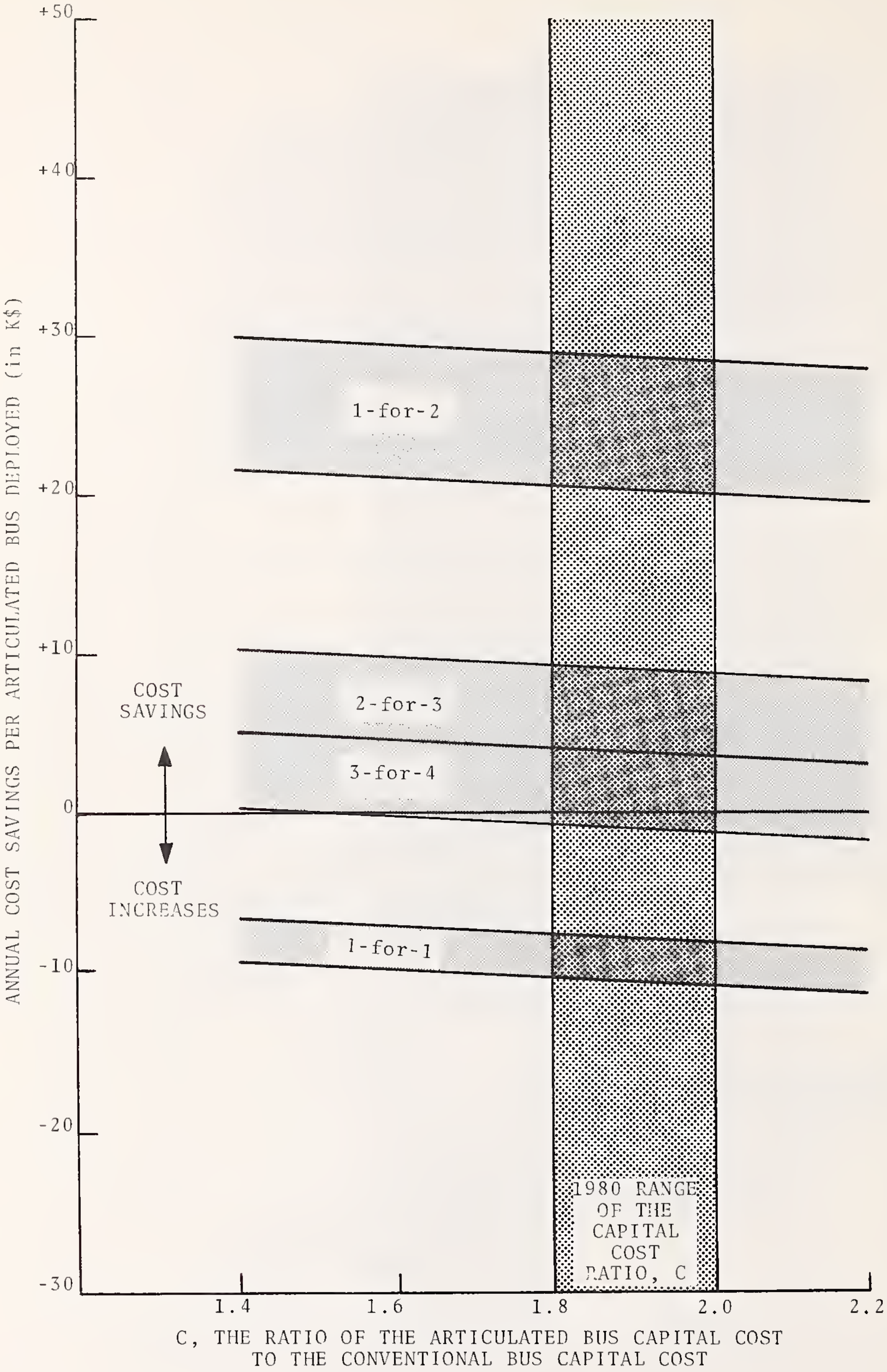

FIGURE 5.6

Annual Cost Savings Resulting From the Subsitution of Articulated Buses for Conventional Buses in All Day Local Service from the Transit Operator's Perspective

### TABLE 5.2

### Summary of the Annual Cost Savings Resulting from the Substitution of Articulated Buses for Conventional Buses in Different Types of Service

(cost savings in $1000's/articulated bus deployed)

| | | peak period express service | | peak period local service | | all day local service | |
|---|---|---|---|---|---|---|---|
| substitution rate | estimate | societal perspective | operator perspective | societal perspective | operator perspective | societal perspective | operator perspective |
| 1-for-2 | high | 37.8 | 32.9 | 33.2 | 28.9 | 50.3 | 41.3 |
| | low | 27.1 | 25.1 | 21.1 | 20.0 | 28.2 | 31.1 |
| 2-for-3 | high | 11.2 | 13.2 | 6.8 | 9.5 | 15.3 | 11.7 |
| | low | 3.4 | 8.0 | ( 2.1) | 3.4 | 4.8 | 5.9 |
| 3-for-4 | high | 2.4 | 6.7 | ( 0.5) | 4.1 | 3.7 | 6.8 |
| | low | ( 4.4) | 2.3 | ( 8.3) | ( 1.0) | ( 5.7) | 0.4 |
| 1-for-1 | high | (14.8) | ( 6.0) | (15.3) | ( 7.3) | (18.2) | ( 9.5) |
| | low | (19.7) | ( 8.8) | (20.9) | (10.7) | (25.7) | (14.3) |

NOTE: Figures in parentheses, i.e., negative cost savings, represent cost increases.

(5) Estimates of cost savings (increases) from the societal and operator perspectives show a significant difference only as the articulated bus substitution rate approaches 1-for-1 (refer back to Table 5.2). At 1-for-1 substitution, where cost increases are produced under all scenarios, the cost increase estimates from the operator perspective are considerably lower than those from the societal perspective. With the sharply higher articulated bus capital costs at this substitution rate, the assumption that the operator is absorbing only 20% of all capital costs (with the Federal government paying the other 80%) has a large impact on reducing the costs that must be charged to articulated bus deployment. In settings where fewer articulated buses are substituted for a given number of conventional buses, differences in capital expenditures resulting from deploying articulated buses instead of conventional buses become small. Under these circumstances, the impact of the assumption of 80% Federal subsidization on the calculation of articulated bus cost savings is also small.

(6) At the 1-for-2 and 2-for-3 articulated bus substitution rates, cost savings are highest when articulated buses are deployed in all day local service (as compared to cost savings with articulated bus deployment in peak period express service or peak period local service). This cost savings advantage stems from the significantly larger savings in both driver and non-driver operating costs possible with all day substitution. As the substitution rate goes toward 1-for-1, the operating cost savings possible with all day substitution diminish, and disappear at 1-for-1 substitution. At the 1-for-1 rate, where cost increases are produced in all cases, use of articulated buses in peak period express service produces the lowest estimates of cost increases due to the lower articulated bus non-driver operating costs in this mode of operation. In peak period express service, articulated buses generally will be operated only in the peak period, while, on local routes, some articulated buses will be in all day service.

(7) At all substitution rates, use of articulated buses in peak period express service produces higher cost savings than using them in peak period local service. This is due to:

(a) Lower per-mile non-driver operating costs for express service.

(b) Higher driver labor cost savings and lower capital costs. The smaller negative impact on bus run time using articulated buses on express versus local routes results in fewer additional drivers and vehicles being needed on express routes to compensate for the smaller travel time increase there.

# 6. COST BENEFIT TRADEOFFS

The preceding section showed that articulated buses provide a means for significantly reducing the costs on some routes. However, the potential exists only for substitution ratios of less than 1-for-1, which means that, in general, any cost reduction must be accompanied by a degradation of at least one aspect of service: wait time. Because bus riders are sensitive to the service characteristics of the route, degradation of service can result in lower ridership, diminished revenues and less pleasant service for those continuing to ride. Thus any analysis of the impact of articulated buses must consider the potential negative service impacts as well as the potential positive cost impacts.

This section will identify relevant service impacts of articulated buses and will discuss ways in which negative and positive impacts can be weighed against each other in an evaluation of the cost-effectiveness of articulated buses in any application. With the aid of a simple analysis procedure and some contrived examples, some situations in which articulated buses appear to hold promise will be identified, as will some situations in which they seem to be inappropriate.

To keep this section simple, all comparisons of articulated buses versus conventional buses will be couched in terms of a "substitution" of articulated buses for conventional buses. This is a journalistic convenience only and does not make the comparisons inapplicable to other situations. For example, a situation in which the fleet size will <u>increase</u>--the only question being whether to add articulated buses or conventional buses--can still be addressed as a "substitution": the substitution comparisons may be interpreted as the differences that would result if articulated buses are added instead of conventional buses. A similar interpretation is available for a <u>decrease</u> in fleet size.

## 6.1 Service Impacts

Substitution of articulated buses for conventional buses will affect the quality of service on the route. This is so regardless of the service level, although the severity of the impacts certainly increases as the substitution ratio decreases (i.e., as fewer articulated buses are substituted for a given number of conventional buses). Among the major service impacts are the following:

> <u>Wait time increases</u>. For any substitution ratio less than 1-for-1, articulated buses will, with one exception, run on longer headways than the buses they replace. This is simply the result of using fewer vehicles. The exception is where a single articulated bus replaces two conventional buses operating jointly as a "double-header." The longer headways produced when articulated buses are substituted at less than a 1-for-1 ratio generally result in longer wait times for passengers. Only when riders coordinate their arrivals at the bus stop with the arrival of the bus does an increase in headways not result in an increase in passenger wait time. Note, however, that these special cases do not

decrease the wait time; they only keep it from rising when articulated buses are used.

- Schedule opportunity losses. Another aspect of an increase in headway is the loss of departure time opportunities: a person who could choose from among 12 trips per hour by conventional bus might have only 8 trips per hour available after a 2-for-3 substitution. With the exception of the double-header case, any substitution ratio of less than 1-for-1 will result in a loss of opportunities. Notice that these opportunities are lost even if the wait time does not increase.

- In-vehicle time increases. One component of bus run time is the time required to board and deboard passengers. To board and deboard a given number of passengers, an articulated bus can be expected to incur a dwell time equal to or slightly greater than that for a conventional bus. Since an articulated bus can be expected to process at least as many passengers as a conventional bus on any given route at any realistic substitution ratio, an articulated bus will always take as long or longer to complete the run, implying that the average passenger will incur as much in-vehicle time or more.

- Schedule reliability impacts. The substitution of articulated buses for conventional buses will probably change the schedule reliability of the route, but the nature of the change is not obvious and very likely depends on the travel characteristics of the roads which the buses use and the profile of ridership volumes along the route. However, because conventional and articulated buses will carry different loads and will travel at different speeds, a local route using a mix of bus types can be expected to provide a lower level of schedule reliability than one using a single type of vehicle.

- Riding comfort impacts. One of the advantages of articulated buses is that a given level of riding comfort can be provided to a fixed number of passengers using fewer vehicles because each vehicle has more seats and more total capacity. However, the level of riding comfort for conventional and articulated buses is equal at a fairly high substitution ratio -- about 2-for-3 if 60-foot articulated buses are used. For lower substitution ratios and equal ridership volumes, the level of riding comfort is lower for articulated buses.

- "Bypass impacts". A bus rider who frequently is bypassed by packed buses as he waits at the bus stop will not be a regular bus patron for long. The probability that a rider will experience a bypass is related to the schedule reliability of the route and to the ratio of ridership to capacity. Since articulated buses offer increased capacity, there is a range of substitution ratios over which the probability of being bypassed can be expected to decline. However, as with the riding comfort level, articulated and conventional buses offer equivalent bypass probabilities at a fairly high substitution ratio -- near 2-for-3 if ridership volumes are constant and 60-foot articulated buses are used. However, ridership will vary in response to the service changes associated with the substitution, so the effect of substitution on the bypass probability is difficult to determine.

Other kinds of service impacts could be identified, but these are ones that have the greatest effect on ridership. For any substitution ratio which saves money, three of the six service measures -- wait time, schedule opportunities and in-vehicle time -- will worsen when articulated buses are used and two of the measures -- riding comfort and bypass probability -- have only a slight chance of improving. The sixth impact -- schedule reliability -- has an indeterminate impact. Consequently, cases in which the use of articulated buses both improves service and decreases costs are very rare. More numerous are the cases in which articulated buses are clearly inferior: service deteriorates and costs increase. However, the vast majority of cases will show articulated buses to offer lower operating costs at the expense of a diminished level of service. In these cases the cost and service impacts must be weighed against each other to determine which dominates.

## 6.2 Comparing Cost and Service Impacts

To compare the cost and service impacts of the use of articulated buses, there must be a way to estimate the cost impacts, a way to estimate the service impacts and a way to relate the estimates to each other. Section 5 provides a way to estimate the cost impacts. This section will discuss ways to estimate service impacts and to compare them with estimated cost impacts. One simple comparison methodology will be described in detail.

Estimating the service impacts of an articulated-for-conventional bus substitution is difficult because the relationships between vehicle type and some service components are only poorly understood and because many of the impacts are interrelated in complex, dynamic ways. The complex, dynamic nature of the relationships is due largely to the involvement of a human element in the systems: most of the service components -- in-vehicle time, reliability, riding comfort and bypass probabilities -- cannot be estimated without knowledge of the volume of ridership. The volume of ridership, in turn, cannot be estimated without knowledge of the level of service provided by the route. In mathematical terms, it is a "simultaneous system."

One way in which this simultaneous system of service impact relationships is complex is that many of the relationships have a "stochastic" or random component. For example, any description of the expected ridership volume must be stochastic because the ridership varies from day to day. Similarly, the run time on any route varies from trip to trip due to varying traffic conditions along the route and varying passenger load levels.

One way to predict the behavior of a stochastic simultaneous system is to "simulate" it. This involves defining all of the relevant mathematical relationships -- including the distributions of values from which the random components are to be drawn -- and repeatedly evaluating the equations. Various measures can be extracted from each application of the simulation and, after many simulations have been completed, these extracted values provide a statistical picture of the expected performance of the system. Simulation can be used in this way to generate estimates of the service quality and ridership to be expected on a specific route operating under specific conditions.

For all practical purposes, such a simulation requires a computer. Programs embodying simulation capabilities of the type needed to analyze an articulated-for-conventional bus substitution exist[1], [2] and are recommended for use whenever precise estimates of impacts are required.

Once estimates of the service impacts of a substitution have been generated, some method must be employed to relate them to the cost impacts so that a comparative evaluation -- and, ultimately, a judgment on the cost-effectiveness of the substitution -- can be made. This is a broad topic that is beyond the scope of this paper. Rather than entering a general discussion, one simple way to reduce these impacts to a common basis will be described here.

The simplest comparison of service and cost impacts is one in which all such impacts are expressed in the same units. Any units would do, but dollars have the advantage of requiring no transformation of the cost measure. A simple comparison of costs and service impacts, then, requires a dollar measure of the service impacts.

One simple way to translate measures of service impacts into dollars is through a measure of user benefits such as is provided by the "consumer surplus" concept.[3] To use the consumer surplus concept to measure the benefits (or disbenefits) of a change in service, all measures of the quality of bus service--the waiting time, the riding time, the comfort of the ride, the schedule reliability and so on--must first be reduced to a single dollar measure called the "generalized price."

The generalized price of a bus trip is directly related to the quality of service provided. If the service gets worse, the price a rider must "pay" will go up and if the service improves, the price will go down. A fare increase, for example, is distasteful to the riding public and this distaste is shown by an increase in the generalized price. A decrease in the frequency of service is similarly distasteful since it results in longer waiting times and lost schedule opportunities and it, too, is reflected in an increase in the generalized price. If a formula for computing the generalized price of transit service perfectly captures the preferences of a rider, then any two service changes--a fare increase and a frequency cutback, for example--which are viewed as being equally bad in the rider's eyes will both produce the same increase in the computed generalized price.

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[1] Jordan, W.C. and M.A. Turnquist, Control of Service Reliability in Bus Transit Networks: Simulation Model User's Manual, Version 2.0, School of Civil Engineering, Cornell University, Ithaca, N.Y., June, 1980.

[2] Waksman, R. and D. Schmeider, "Bus Route Simulation Models for Studying Service Improvement Strategies," Transportation Systems Center Staff Study No. SS-24-U.S-137, November 1977.

[3] See Appendix C for a discussion of the consumer surplus concept.

Obviously, the generalized price of a bus ride as perceived by a particular rider depends very much on the particular characteristics of the bus trip (Did it arrive on time? Was the bus crowded?), the preferences of the particular traveller (How much is a minute of waiting time worth? How much would he/she be willing to pay to sit?) and a number of other factors (Is it raining?). In practical terms, the true generalized price of a particular trip to a particular rider is incalculable. However, by making a number of assumptions, it is possible to establish a formula for computing a crude estimate of the average generalized price faced by all persons considering using a specific bus service.

A single measure of all aspects of the level of bus service--as provided by a generalized price formula--can serve as the basis for a simple model of bus ridership. Such a model can be used to predict how bus riders will respond to changes in any aspect of the level of service.

Appendix D describes a demand model based on the generalized price concept that will be used later in this chapter to predict the probable ridership impacts of the introduction of articulated buses. Among the numerous assumptions implicit in this model are the following major ones:

- all riders place the same values on service components; and
- the generalized price is the sum of prices of the separate service components.

This model includes most of the factors usually regarded as important in determining bus ridership, including fare, travel time, wait time, the probability of getting a seat (one aspect of riding comfort) and the probability of being bypassed by a full bus (one aspect of schedule reliability). However, many other factors which could have been included have been left out. Appendix D contains further details.

This model may not be the best of all possible demand models for predicting demand impacts of bus service changes, but it is reasonable model form for this application and is proof that the "generalized price" concept is viable. It is a rational model which, together with the "consumer surplus" concept, provides the basis for a simple comparison of costs and benefits of an articulated-for-conventional bus substitution.

How can such a comparison be accomplished? First, it is possible to calculate the change in consumer surplus resulting from the change in the level of service. The change in this measure of user benefits can then be compared to the change in capital and operating costs associated with the change in service. If the difference in the change in benefits and the change in costs is positive, then the change in service may be regarded as being cost-effective.[4]

It should be noted that the change in costs resulting from a change in service can be viewed from several different perspectives. If all costs are considered, then the change in costs is viewed from society's perspective because the public eventually--directly in fares or indirectly in taxes--ends up footing the bill. If only the costs borne by the operator are considered, then the change in costs is viewed from the operator's perspective.

Both perspectives are relevant in a cost/benefit analysis involving articulated buses. The societal view--in which societal gains (losses) in user benefits are weighed against increased (decreased) costs--is the view taken by the government which must decide whether to promote the change by subsidizing it. The operator, on the other hand, must compare the increased (decreased) costs against increased (decreased) revenues and decide whether the change is worthwhile from the transit company's perspective. A public-spirited operator will look beyond a simple cost/revenue analysis and consider user benefits and intangible benefits to the community as well. However, there is no simple way to incorporate all such considerations into a cost/benefit analysis. Still, a comparison of operator costs and societal benefits (i.e., consumer surplus) can be regarded as providing an evaluation boundary: any change in service which results in societal benefits which exceed the operator costs must be regarded as being potentially cost-effective.

Both perspectives are used in the following section to evaluate the effectiveness of articulated buses in a variety of hypothetical situations.

## 6.3 Some Articulated Bus Scenarios

The simple analysis methodology described in the preceding section affords a means for evaluating the cost-effectiveness of articulated buses. This methodology has been used to investigate the cost/benefit tradeoffs experienced in some specific cases. Limited resources prevented the analysis of any actual cases; rather, a number of realistic scenarios were developed and analyzed with service impacts being estimated subjectively using "professional judgment." The demand model described in Appendix C was employed to estimate ridership responses to the service changes and the service

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[4] However, other factors not accounted for in the consumer surplus concept should also be considered before reaching a final judgment. The consumer surplus measure does not account for the activities undertaken by those persons who leave the bus system because the cost rises or for the activities previously performed by those who enter the system because the price falls. For example, if a person is drawn out of a private automobile by a drop in the price of bus service, then there may be economic benefits to society (e.g., environmental benefits) far in excess of the small incremental change in consumer surplus attributable to that person. There is no easy way to estimate these "external" benefits.

measures and demand volumes were iteratively adjusted until judged to be in accord.

Clearly, the results of this analysis cannot be regarded as providing definitive evidence for or against articulated buses. Still, the service impact estimates are reasonable and the demand model behaves rationally, leading one to suspect that the results of this analysis may give some valid insights into the cost-effectiveness of articulated bus utilization. Of course, a more detailed analysis should be performed before drawing any conclusions in any specific case.

In all of the cases to follow, the route initially operates with a fleet of 40 foot conventional buses having 50 seats and room for 80 passengers in all. The service change in all cases involves the use of 60-foot articulated buses in place of part or all of the conventional bus fleet. Each articulated bus has 71 seats and a total capacity of 124. Two cost estimates, derived from the high and low cost savings ranges established in Section 5 (see Table 5.2) have been produced for each case. Since the objectives of these scenarios is to illustrate cost/benefit tradeoffs associated with articulated buses, the fares have been held constant.

The following cases were analyzed:

A. Local Bus: a high-density, short-headway, all day route
    A1. Substitute 1:1 all day
    A2. Substitute 3:4 in the peak period (for part of the fleet only)
    A3. Substitute 2:3 all day
B. Express Bus: a peak period, point-to-point, medium-headway route
    B1. Substitute 1:1
    B2. Substitute 2:3
    B3. Substitute 1:2
C. Double-Header Express: a single two-bus run
    C1. Substitute 1:2

A few additional cases were analyzed using different demand model assumptions to demonstrate the sensitivity of the analysis to those assumptions.

### 6.3.1 Scenario A: Local Bus

A 5-mile local bus route having 40 scheduled stops operates from 6 a.m. to 8 p.m. weekdays. The average end-to-end run time is 28 minutes in the peak direction in the peak period (7 to 9 in the morning and 4 to 6 in the evening) and 21 minutes in the peak period reverse direction and in both directions, at all other times.

Currently 12 conventional buses serve this route on 5-minute headways in the peak and 6 buses operate on 8-minute headways in the offpeak. Daily ridership stands at 4800 for the peak period peak direction (48 runs), 1920 in the peak period reverse direction (48 runs) and 4500 in the offpeak (150 runs). The demand in each period can be assumed to be relatively flat and the bus runs are evenly spaced. Assuming an even passenger arrival rate, the average wait time is 2.5 minutes in the peak and 4.0 minutes in the offpeak.

The average passenger in-vehicle time is 20 minutes in the peak period peak direction and 15 minutes otherwise. The fare is $.50 all day. In the peak period peak direction the probability of sitting is .60, but is 1.0 in the reverse peak direction and .95 offpeak. There is a 3% chance of getting bypassed in the peak period peak direction, but no chance otherwise. These conditions are summarized in Figure 6.1. Using the generalized price formula given in Appendix C, the following service prices can be computed:

peak period peak direction : $1.6425
peak period reverse direction: $1.2875
offpeak : $1.4075

#### 6.3.1.1 Option A1: 1-for-1 Substitution All Day

If all of the conventional buses are replaced on a 1-for-1 basis with articulated buses, a total of 12 buses are needed, six of which are used in the offpeak. The expected wait times do not change and the average travel time increases only slightly in the peak period peak direction (to 21 minutes) and not at all otherwise. The probability of sitting, however, increases significantly due to the increased hourly seat capacity -- up to .80 in the peak period peak direction and 1.0 in the offpeak. The probability of getting bypassed in the peak period peak direction can also be expected to drop significantly -- down to .01. These changes are summarized in Figure 6.2.

These new service levels translate into the following generalized prices and volumes (changes from all-conventional bus base case are shown in parentheses):

peak/peak : $1.5945 (-$.0480); 4940 (+140)
peak/reverse: $1.2875 (0) ; 1920 (0)
offpeak : $1.4000 (-$.0075); 4520 (+120)

These price changes in turn result in the following changes in user benefits:

peak/peak : +233.76/day
peak/reverse: no change
offpeak : +33.83/day
±$267.59/day

Assuming 250 weekdays per year, this gives an annual increase in user benefits of about $66,900.

However, the articulated buses have a higher annual cost. Estimates of the extra cost involved range from $257,700 per year to $363,900 per year. The net result is a societal loss of between $190,800 and $297,000 annually.

From the operator's point of view the cost impacts are significantly reduced with the cost increase ranging from $134,500 to $202,500 per year. This cost increase is only partially offset by an annual revenue increase of about $20,000, leaving a net loss of from $114,500 to $182,500 per year. A

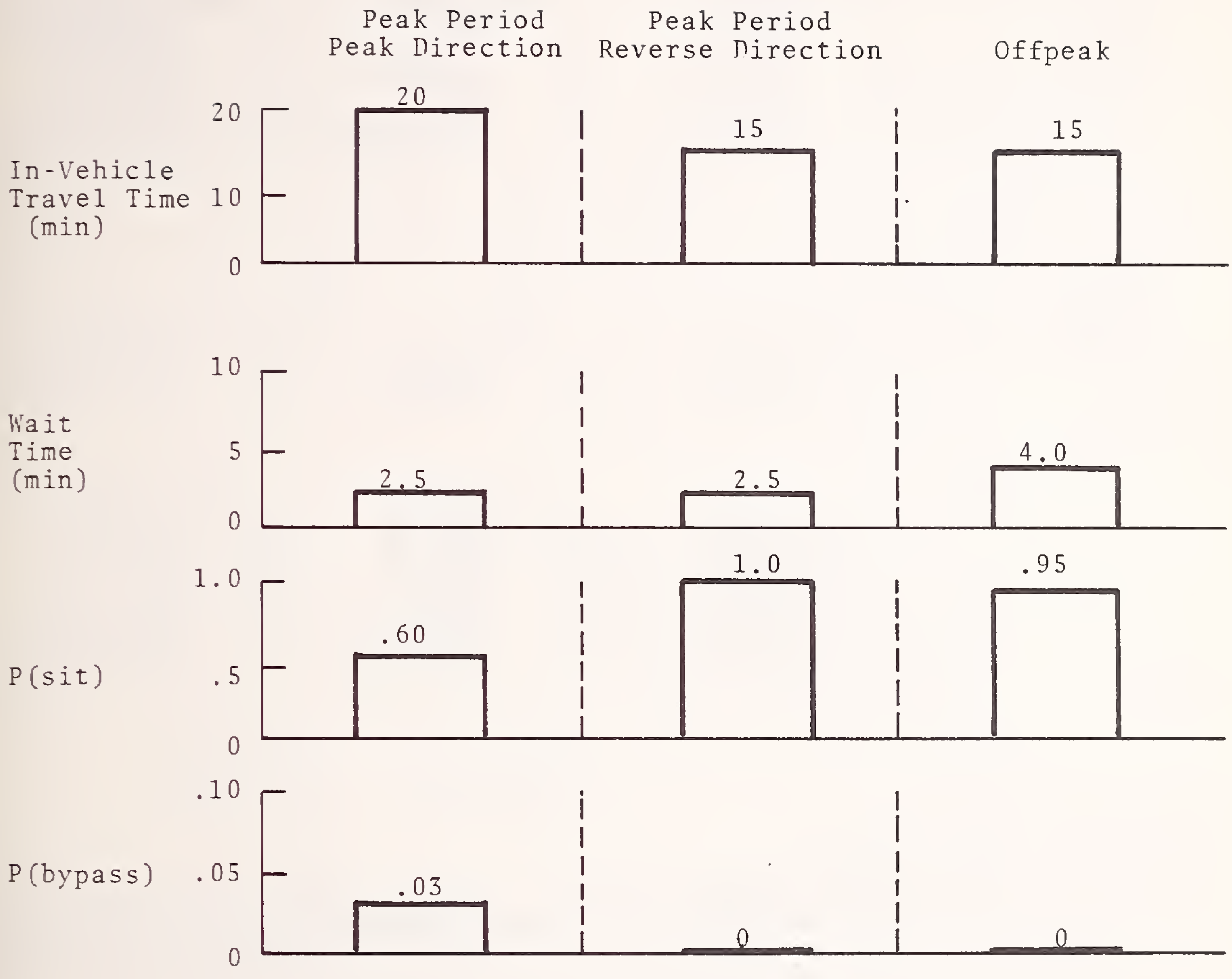

FIGURE 6.1

Local Bus Scenario: Existing Service

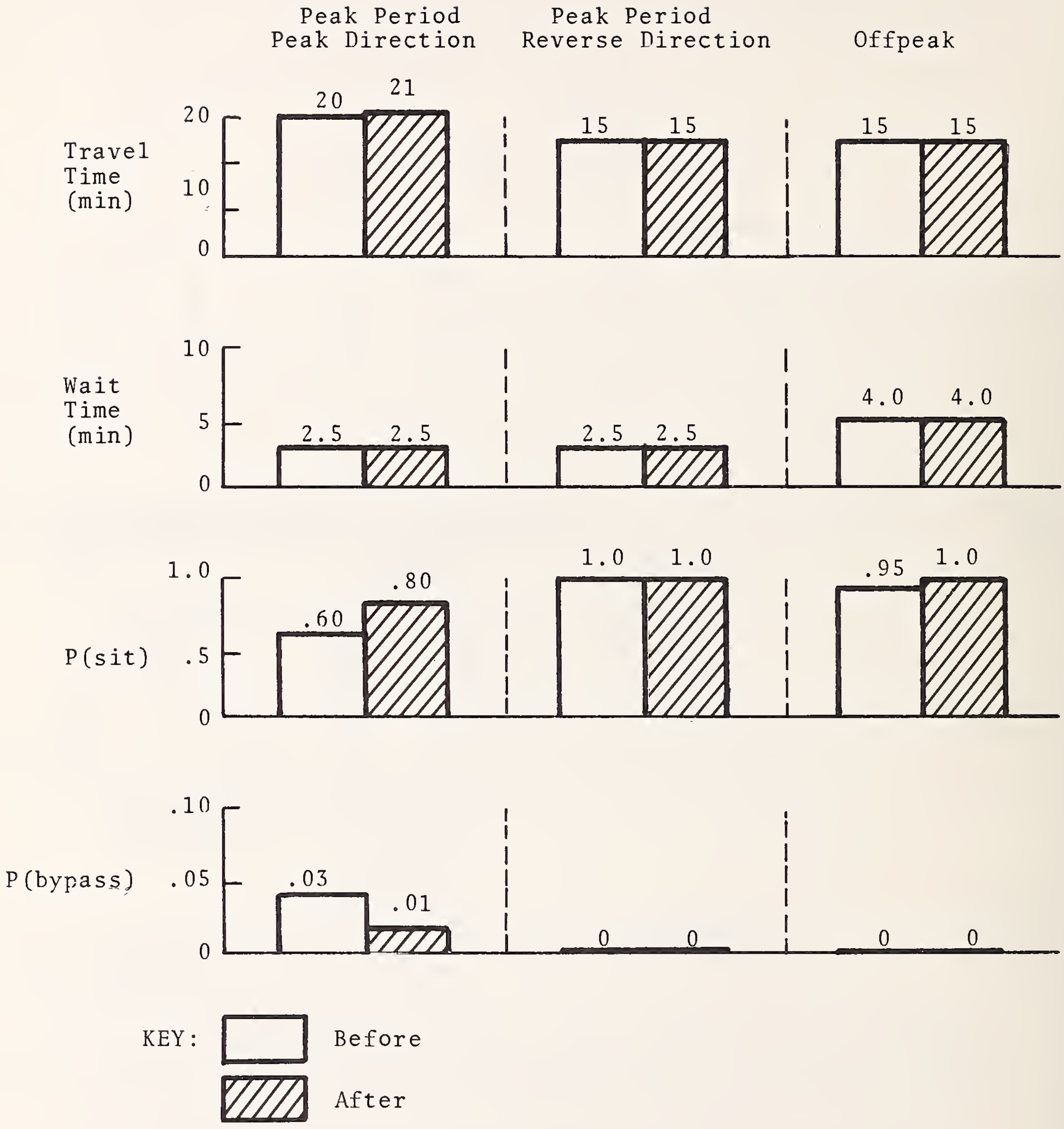

FIGURE 6.2

Local Bus Scenario: 1-For-1 Substitution comparison of operator costs and user benefits also shows a net loss in the range from $67,600 to $135,600 per year.

### 6.3.1.2 Option A2: 3-for-4 Peak Substitution, Mixed Fleet

In this option, 6 articulated buses replace 8 conventional buses in the peak period, giving a peak period fleet of 6 articulated and 4 conventional buses. Six buses continue to be used in the offpeak, two of which are articulated buses. In the peak period five of every six articulated bus trips are preceded by a 7-minute headway; all other trips are preceded by 5-minute headways.

The fare does not change under this arrangement, but all of the other service components change significantly. The average peak/peak travel time increases to 21.5 minutes and to 16 minutes otherwise. The peak/peak wait time increases to 3.1 minutes (computed assuming an even distribution of arrivals: (35*3.5+25*2.5)/60). The probability of sitting increases slightly to .66 in the peak period peak direction and to .97 in the offpeak due to an increase in seat capacity (from 600 to 697 per hour in the peak and from 375 to 428 per hour offpeak). The peak/peak probability of getting bypassed decreases to .01 due to an increase in total peak period peak direction capacity (from 960 to 1064 per hour). These changes are summarized in Figure 6.3.

The demand model predicts the following new prices and volumes as a result of these service changes:

peak/peak : $1.6988 (+$.0563); 4641 (-159)
peak/reverse: $1.3725 (+$.0850); 1825 (-95)
offpeak : $1.4448 (+$.0373); 4400 (-100)

These figures in turn result in the following changes in daily user benefits:

peak/peak : -$265.76/day
peak/reverse: -$159.16/day
offpeak : -$165.99/day
-$590.91/day

for an annual user benefit loss of about $147,700. These changes result in a annual cost increase of about $3,500 to $58,800, giving a net loss to society of $151,200 to $206,500 per year.

The operator would experience a cost impact in this case that ranges from an annual $7,100 cost increase to a $29,000 annual cost savings. The 354 lost daily riders implies an annual revenue drop of about $44,300, giving a net annual operator loss lying somewhere between $15,300 and $51,400.

Comparing these operator cost impacts with the user benefit impacts reveals a net loss ranging from $118,700 to $154,800 annually.

### 6.3.1.3 Option A3: 2-for-3 Substitution All Day

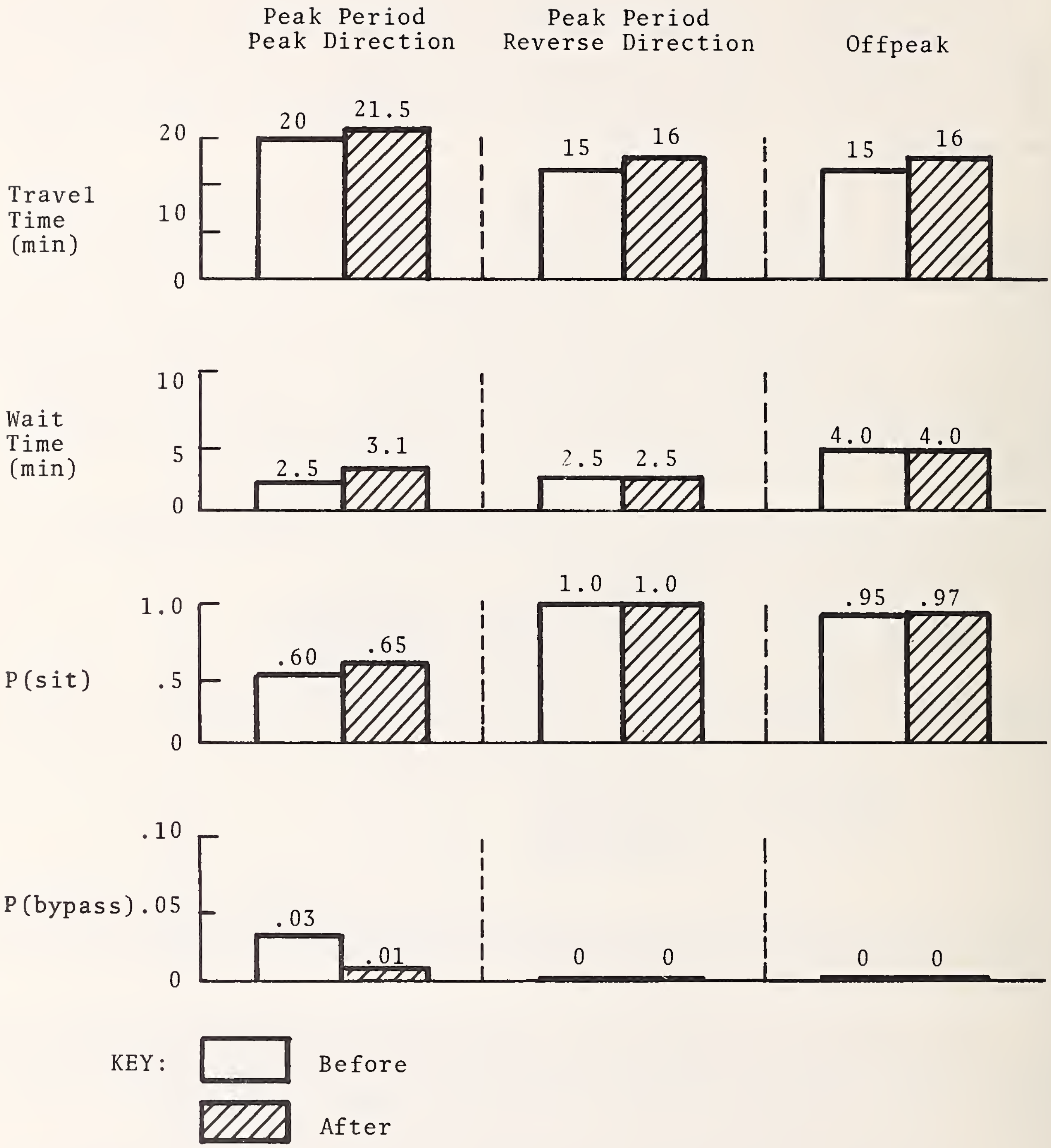

FIGURE 6.3

Local Bus Scenario: 3-For-4 Peak Substitution

In this option 8 articulated buses replace the 12 conventional buses. All eight run in the peak periods and 4 run offpeak (replacing the 6 conventional buses then). The average in-vehicle travel time increases to 22 minutes in the peak period peak direction and to 16 minutes otherwise. The peak/peak probability of being bypassed drops to .02, but the wait time rises sharply -- to 3.75 minutes in the peak and to 6.0 minutes offpeak. The probability of sitting will increase to .66 in the peak period peak direction and to .97 in the offpeak due to the decline in ridership caused by the other service changes. Figure 6.4 illustrates these service changes.

These service changes -- especially the increase in expected wait time -- translate into large increases in the generalized price of the service and corresponding large decreases in volumes:

peak/peak : \$1.8111 (+\$.1686); 4338 (-462)
peak/reverse: \$1.4213 (+\$.1338); 1772 (-148)
offpeak : \$1.5948 (+\$.1873); 4022 (-478)

The price in volume changes result in the following changes to daily user benefits:

peak/peak : -\$770.33/day
peak/reverse: -\$246.99/day
offpeak : -<u>\$798.09/day</u>
-\$1815.41/day

This gives an annual user benefit loss of about \$453,900. The cost savings realized from this substitution range from \$45,300 to \$144,400 giving a net annual societal <u>loss</u> of \$309,500 to \$408,600. The corresponding operator cost savings range from \$55,700 to \$110,400 per year. These cost savings are offset by revenue losses of about \$136,000 per year, leaving a net <u>loss</u> ranging from \$25,600 to \$80,300 annually. A comparison of operator cost savings and user benefit losses yields a net <u>loss</u> of \$343,500 to \$398,200 annually.

### 6.3.2 Scenario B: Express Bus

A 15-mile direct express route (i.e., one having no intermediate stops) operates during weekday peak hours only (two a.m. hours and two p.m. hours). During those hours, six conventional buses operate on 10 minute headways. The trip takes 30 minutes in the peak direction and 20 minutes in the reverse direction. The 24 daily peak direction runs carry 1440 passengers (an average of 60 passengers per run) while the reverse runs carry about 240 passengers per day (10 per run average). Demand is triangular with the peak demand occurring in the middle of the two-hour peak period (see Figure 6.5). The probability of sitting is .78 in the peak direction and 1.0 in the reverse direction. The probability of getting bypassed is .028 in the peak direction and zero for the reverse trips. The current fare is \$1.50 each way.

These conditions translate into the following generalized prices:

peak direction : \$3.2810

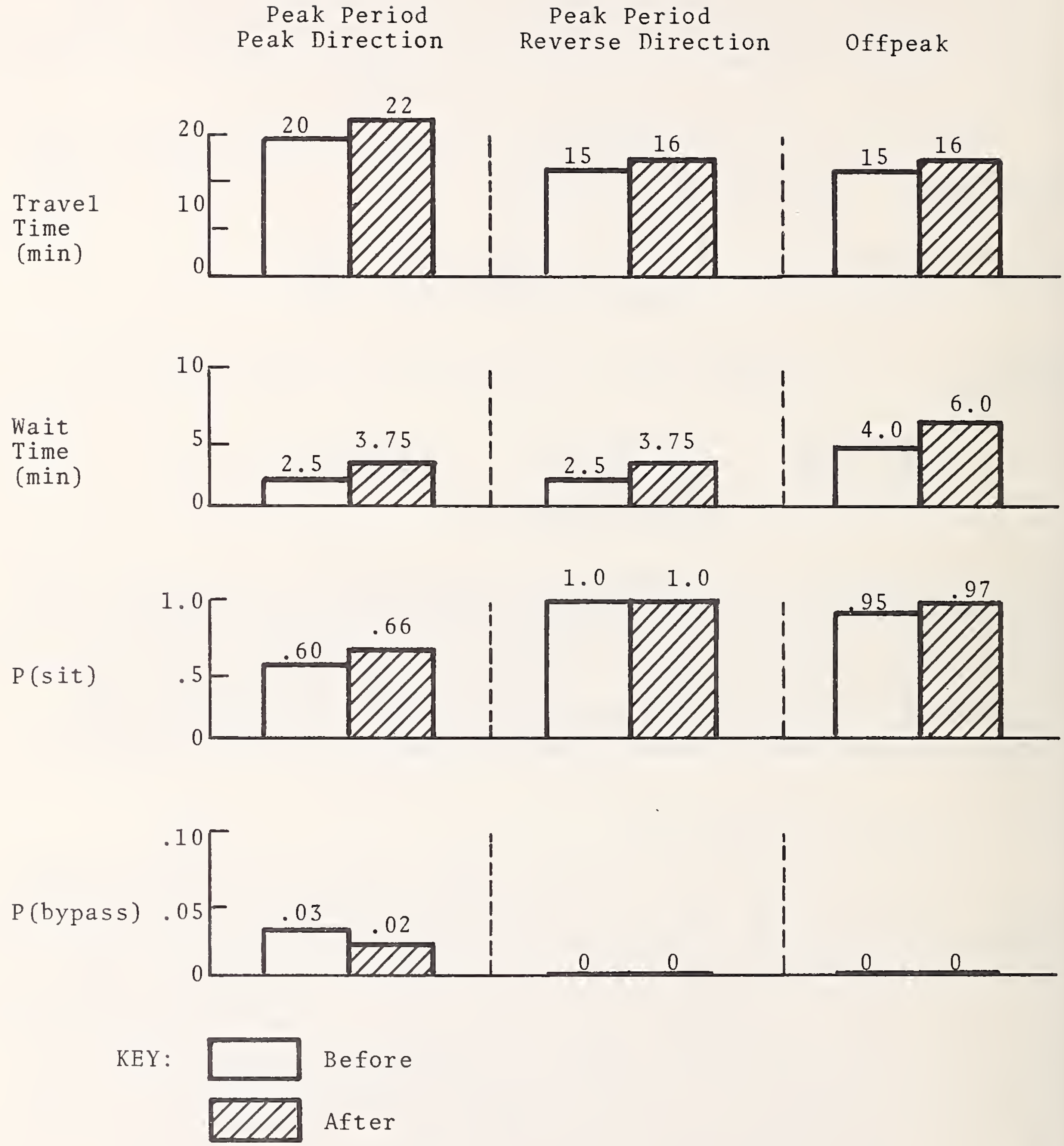

FIGURE 6.4

Local Bus Scenario: 2-For-3 Substitution

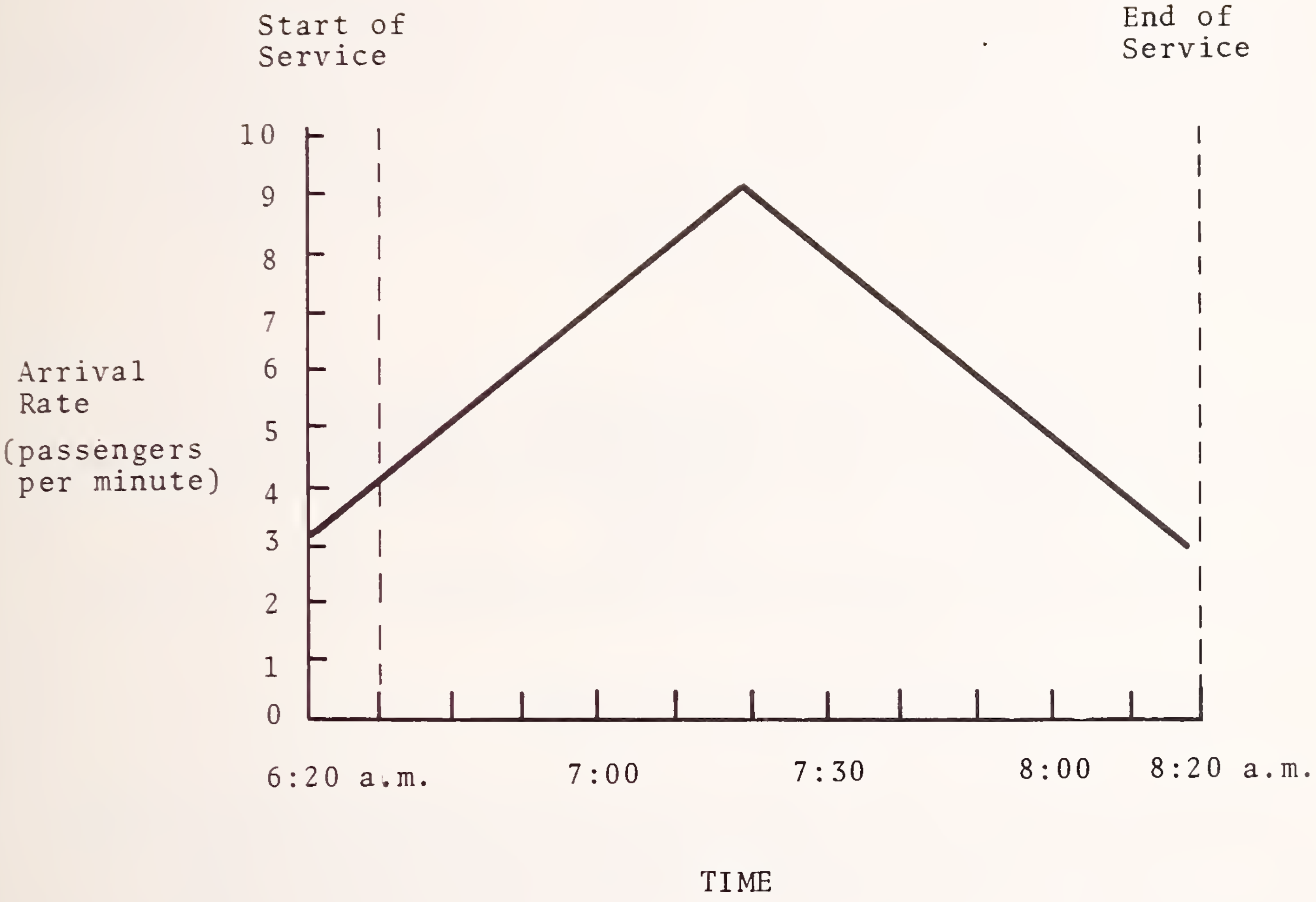

FIGURE 6.5

Express Bus Scenario: Existing Demand

reverse direction: $2.6750

### 6.3.2.1 Option B1: Substitute 1-for-1

This option replaces all 6 buses in the fleet with articulated buses. The fare, travel times and wait times do not change. The peak direction probability of sitting increases to .94 while the probability of getting bypassed diminishes to zero. Figure 6.6 illustrates these changes.

Inserting these values into the demand model results in the following generalized prices and demand volumes:

peak : $3.0930 (-$.1880); 1495 (+55)
reverse: $2.6750 (0) ; 240 (0)

These figures translate into a daily increase in user benefits of about $275.89, or about $69,000 per year. The cost of implementing this option is probably between $104,800 and $139,500 per year, giving a net societal loss of between $35,800 and $70,500 annually. The annual gain in revenue is about $20,600 which, coupled with operator cost increases of from $42,500 to $62,300, translates into a net annual operator loss of from $21,900 to $41,700. If operator costs are compared with user benefits, however, a net annual gain of from $6,700 to $26,500 is revealed.

### 6.3.2.2 Option B2: Substitute 2-for-3

In this option the 6 conventional buses are replaced with 4 articulated buses. The fare and travel times remain the same. Expected wait time increases to 7.5 minutes and the peak direction probability of sitting drops to .76. The probability of being bypassed drops to .005. These changes are illustrated in Figure 6.7.

The demand model translates these service measures into the following generalized prices and volumes:

peak : $3.3720 (+$.0910); 1414 (-26)
reverse: $2.8625 (+$.1875); 231 ( -9)

These, in turn, translate into a daily loss in user benefits of $174.02 or about $43,500 annually. This option results in operating and capital cost savings of from $16,000 to $52,900 a year, giving a net annual impact to society ranging from a $27,500 loss to a $9,400 gain. The operator experiences annual cost savings of from $37,800 to $62,300 and revenue losses of about $9,800, giving net annual operator gains in the range from $28,000 to $52,500. Comparing operator cost savings with losses in user benefits reveals a net impact ranging from an annual loss of $5,700 to a gain of $18,800 per year.

### 6.3.2.3 Option B3: Substitute 1-for-2

Three articulated buses replace the six conventional buses in this option. The fare and in-vehicle travel times are unchanged. Average wait

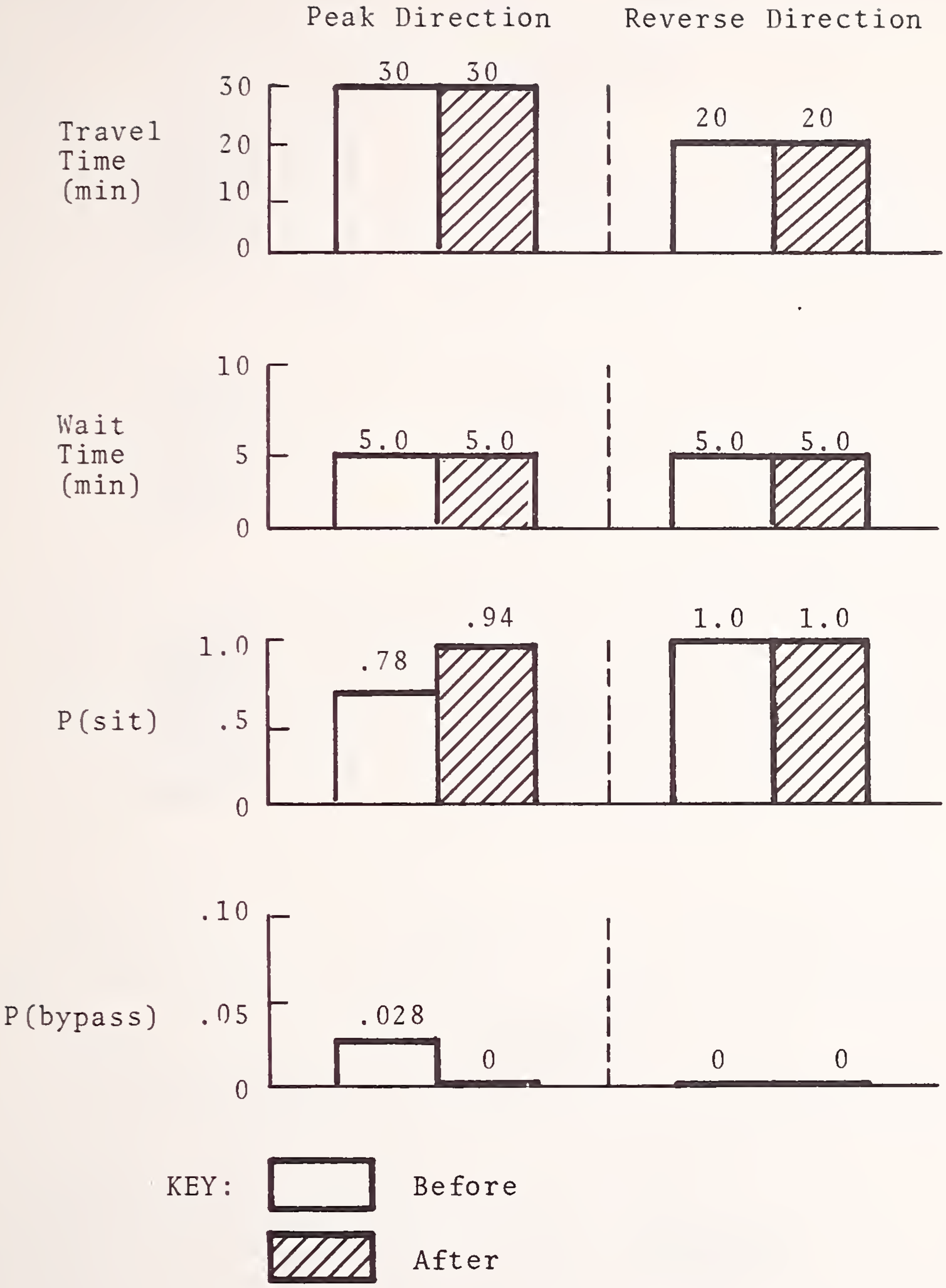

FIGURE 6.6

Express Bus Scenario: 1-For-1 Substitution

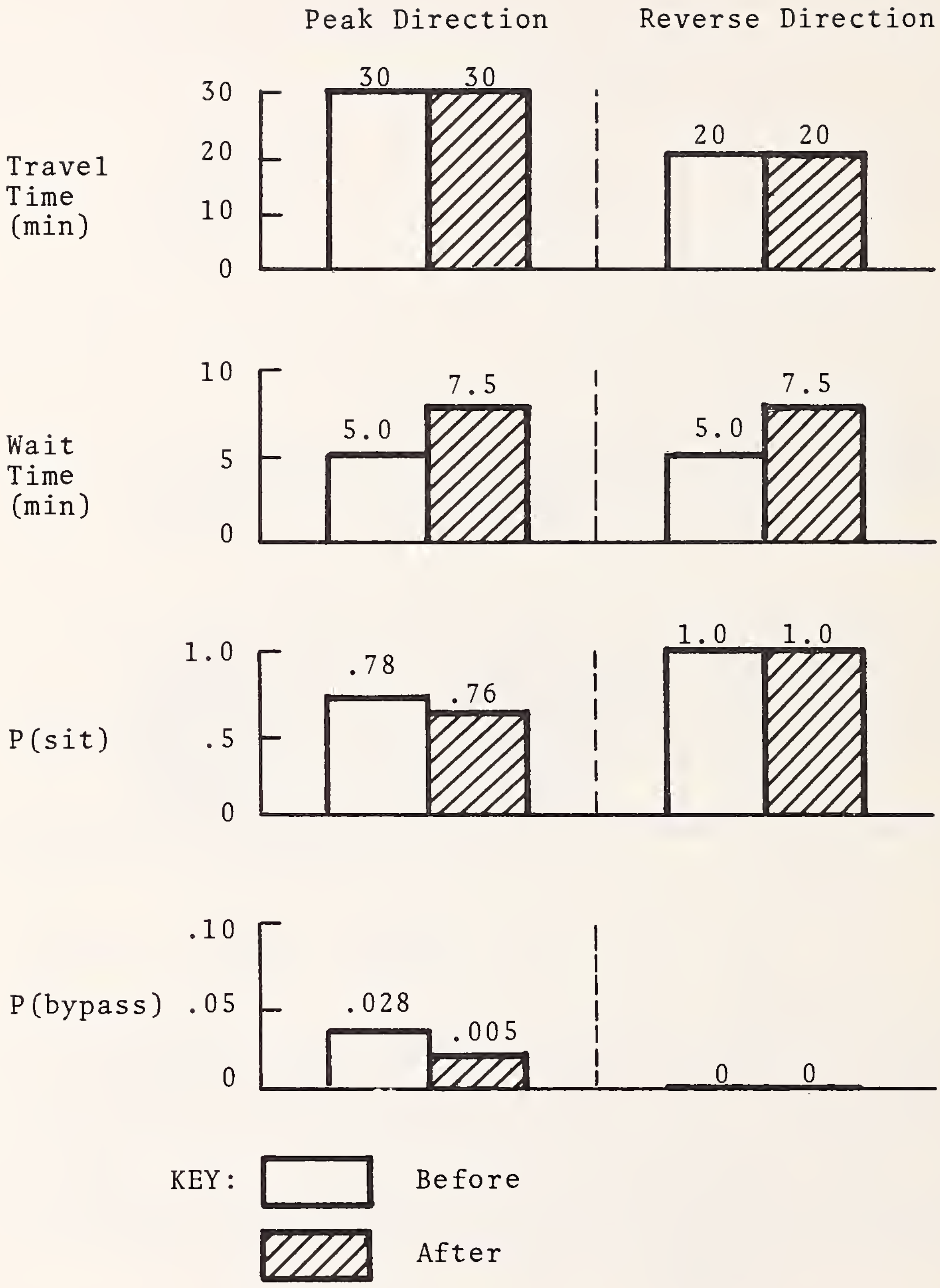

FIGURE 6.7

Express Bus Scenario: 2-For-3 Substitution

time doubles to 10 minutes, causing a significant drop in ridership. However, due to the even greater drop in seat capacity (the number of seats per hour drops from 300 to 213), the probability of sitting falls to .68. The probability of being bypassed rises to .074 due to the large drop in total capacity (from 240 per hour to 186). These service changes are summarized in Figure 6.8.

The decrease in service is reflected in the following generalized prices and volumes:

peak : \$4.2860 (+\$1.0050); 1178 (-262)
reverse: \$3.0500 (+\$.3750); 223 (-17)

These figures translate into daily user benefit losses of \$1315.55 in the peak and \$86.81 offpeak for an annual loss of about \$350,600. The cost savings associated with this option are in the range from \$95,900 to \$133,800 annually, giving a net annual loss to society somewhere between \$216,800 and \$254,700. The revenue loss of about \$104,600 per year is offset by the operator cost savings which are between \$88,900 and \$116,500 per year, giving a net annual operator impact lying between a \$15,700 loss and a \$11,900 gain. Comparing operator cost savings with user benefit losses gives a net loss of from \$234,500 to \$261,700 per year.

### 6.3.3 Scenario C: Double-Header

Due to the existence of a very well-defined and sharply peaked demand, a 15-mile direct express route operates only one morning and one evening run. However, the demand is high for those runs (about 100 each way), so two conventional buses are run as a "double-header." The travel time is 30 minutes and the riders wait an average of 5 minutes. The one-way fare is \$1.50. There is no chance of being bypassed and the probability of sitting is .99.

The generalized price for this service is \$3.0780.

#### 6.3.3.1 Option C1: Substitute 1-for-2

The two conventional buses are replaced with a single articulated bus. The fare, travel time, wait time and probability of being bypassed are all unchanged. Only the probability of sitting is altered -- from .99 to .72. These service changes are illustrated in Figure 6.9.

The new service has a generalized price of \$3.1590 and attracts 197 riders (a loss of 3). This translates into a daily user benefit loss of \$16.08 or about \$4,000 annually. The cost savings from this substitution, however, are probably between \$32,000 and \$44,600 a year, giving a net gain to society of \$28,000 to \$40,600 annually. The operator stands to save from \$29,600 to \$38,800 per year and will lose only \$1,100 in revenue annually, leaving a net gain to the operator of \$28,500 to \$37,700 per year. A comparison of operator cost savings and user benefit losses also reveals a net gain of from \$25,600 to \$34,800 per year.

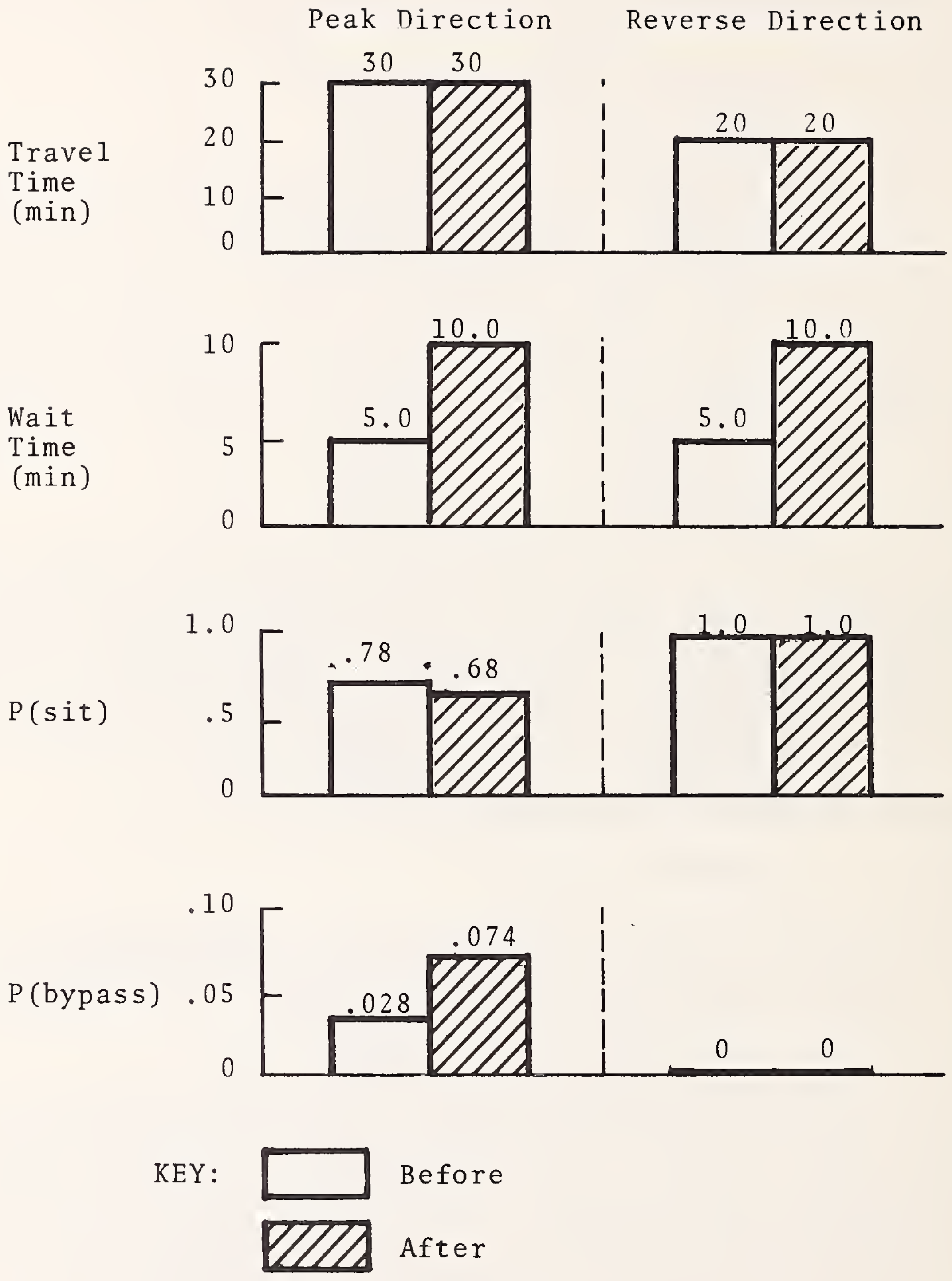

FIGURE 6.8

Express Bus Scenario: 1-For-2 Substitution

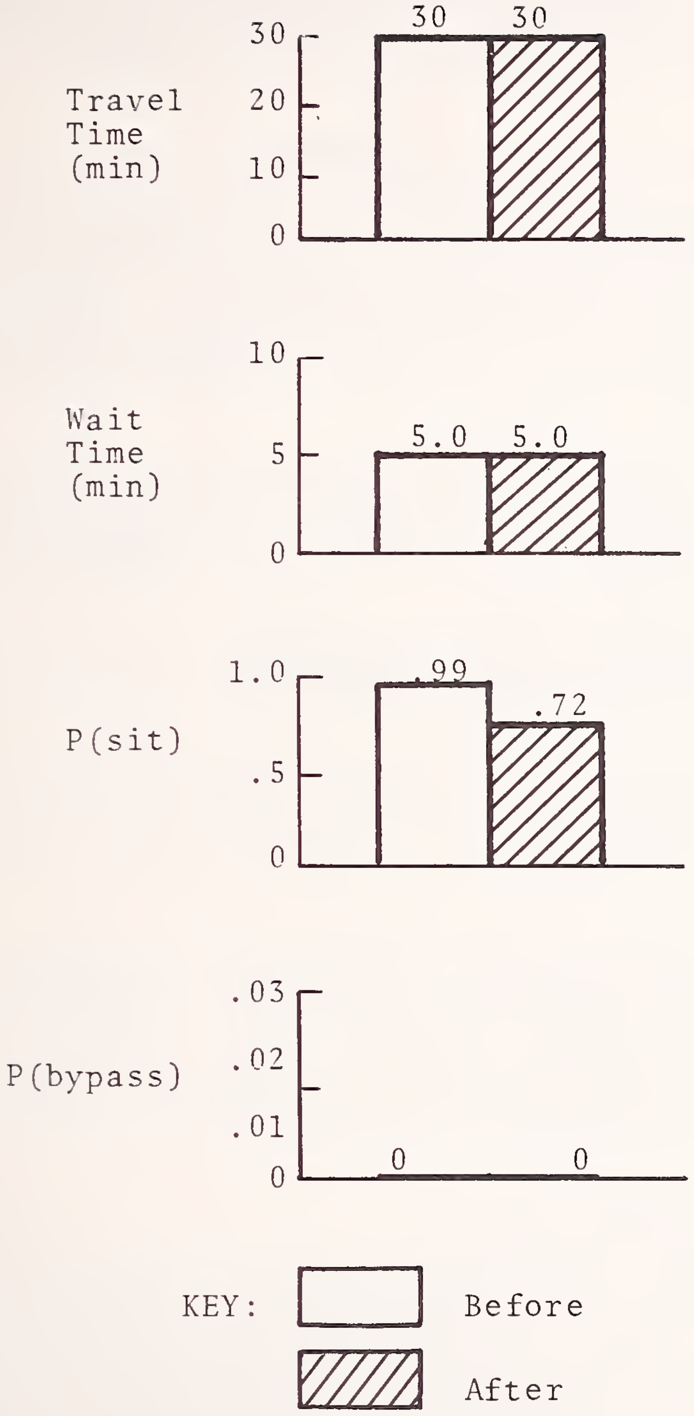

FIGURE 6.9

Double Header Scenario: 1-For-2 Substitution

## 6.4 Sensitivity Analysis

The analysis methodology employed in the preceding sections relies on many assumptions. As with any analysis methodology, the sensitivity of the analysis results to these assumptions should be measured and should be considered in reporting the results. Resource constraints do not permit a full assessment of the sensitivity of the analysis methodology used here, but a couple of examples have been constructed to illustrate the methodology's sensitivity to some of the key analysis parameters. Specifically, the importance of the value-of-time assumptions and the base case volumes will be illustrated.

### 6.4.1 Sensitivity to Value-of-Time Assumptions

Suppose that the demand model (Appendix C) incorporated the assumptions that in-vehicle travel time is worth $1.50 an hour and wait time is worth $3.00 an hour (instead of the $3.00 and $4.50 per hour, respectively, assumed in the calculations). How would that change the results of the preceding analyses? As a case in point, consider Option B3 (the express bus scenario with 1-for-2 substitution).

The base case generalized prices would be $2.4060 for the peak direction and $2.0500 for the reverse direction. The 1-for-2 substitution prices and volumes would be:

peak : $3.383 (+$.9770); 1184 (-256)
reverse: $2.3000 (+$.2500); 228 (-12)

These figures translate into a daily loss in user benefits of about $1340.32 or about $335,100 per year. The cost savings are still in the range of $95,900 to $133,800 annually, giving a net annual societal loss of from $201,300 to $239,200.

Under the original value of time assumptions this option resulted in an annual societal loss of from $216,800 to $254,700. The difference is substantial, but so is the change in value-of-time. Whether the model is sensitive or insensitive to these parameters can be argued, but it is clear that large changes in the parameters do not cause wild fluctuations in the user benefits.

### 6.4.2 Sensitivity to Ridership Levels.

Suppose that the express bus scenario (B) had base case peak direction loads of 1320 instead of 1440. Assuming the same triangular distribution of arrivals, this implies an increase in the base peak direction probability of sitting from .78 to .82 and a decrease in the probability of being bypassed from .028 to .005. These service levels, in turn, imply generalized prices of $3.1540 in the peak direction and $2.6750 in the reverse direction.

As an example of the effect these changes would have on the analysis results, consider Option B3 (the 1-for-2 substitution). The use of articulated buses would increase the waiting time as before from 5.0 to 10.0

minutes. The probability of sitting would drop to .70 and the probability of being bypassed would increase to .048. These changes would be reflected in a peak direction generalized price of $4.0200 and a peak direction volume of 1110 (-210). These figures translate into a daily loss in user benefits of about $1139.00 or about $284,800 per year.

Comparing this figure to the original user benefit loss of about $350,600 per year shows that the analysis results are sensitive to the assumed ridership levels, but only moderately so in this case.

## 6.5 Summary

This section has considered some of the ways in which a substitution of articulated for conventional buses can be expected to affect the quality of transit service. It has also demonstrated one simple way to compare these service impacts and the cost impacts. A number of scenarios were constructed to demonstrate the nature of the tradeoffs involved. The results of these scenarios are summarized in Tables 6.1, 6.2 and 6.3. The computed generalized prices are summarized in Table 6.4.

It was also shown that the results presented in this table are sensitive to the assumptions underlying the analysis methodology. These particular results should thus be viewed with caution; they should be regarded as providing a general indication of situations in which articulated buses are useful (e.g., they are clearly useful in "double-header" situations and are more useful on an express route than on a local route having the same headway) and as examples of the kind of tradeoff analysis that can be performed whenever articulated buses are being considered.

TABLE 6.1

Summary of Societal Tradeoff Analysis Results

| | (1) | (2) | | (3)=(1)+(2) | | (4) | (4)=(3)/(4) | |
|---|---|---|---|---|---|---|---|---|
| OPTION | ANNUAL GAIN IN USER BENEFITS[1] ($x1000) | ANNUAL COST SAVINGS[2] ($x1000) | | NET ANNUAL SOCIETAL GAIN[3] ($x1000) | | BUSES PURCHASED[4] | NET ANNUAL SOCIETAL GAIN PER BUS PURCHASED[5] ($x1000) | |
| | | low | high | low | high | | low | high |
| Local Bus Options: | | | | | | | | |
| 1. 1:1 | 66.9 | (363.9) | (257.7) | (297.0) | (190.8) | 14.16 | (21.0) | (13.5) |
| 2. 3:4 Peak, Mixed Fleet | (147.7) | ( 58.8) | ( 3.5) | (206.5) | (151.2) | 7.08 | (29.2) | (21.4) |
| 3. 2:3 | (453.9) | 45.3 | 144.4 | (408.6) | (309.5) | 9.44 | (43.3) | (32.8) |
| Express Bus Options: | | | | | | | | |
| 1. 1:1 | 69.0 | (139.5) | (104.8) | ( 70.5) | ( 35.8) | 7.08 | (10.0) | ( 5.1) |
| 2. 2:3 | ( 43.5) | 16.0 | 52.9 | ( 27.5) | 9.4 | 4.72 | ( 5.8) | ( 2.0) |
| 3. 1:2 | (350.6) | 95.9 | 133.8 | (254.7) | (216.8) | 3.54 | (71.9) | (61.2) |
| Double-Header Options: | | | | | | | | |
| 1. 1:2 | ( 4.0) | 32.0 | 44.6 | 28.0 | 40.6 | 1.18 | 23.7 | 34.4 |

NOTES:

1. Parentheses indicate a loss of benefits.
2. Parentheses indicate a cost increase.
3. Parentheses indicate a net societal loss.
4. Includes buses out of service due to maintenance requirements and the need for spares.
5. The median net annual societal gain is used.

## TABLE 6.2

### Summary of Operator Cost/Revenue Tradeoff Analysis Results

| OPTION | ANNUAL GAIN IN REVENUES[1] ($x1000) | ANNUAL COST SAVINGS[2] ($x1000) | | NET ANNUAL OPERATOR GAIN[3] ($x1000) | | BUSES PURCHASED[4] | NET ANNUAL OPERATOR GAIN PER BUS PURCHASED[5] ($x1000) |
|---|---|---|---|---|---|---|---|
| | | low | high | low | high | | |
| Local Bus Options: | | | | | | | |
| 1. 1:1 | ( 20.0) | (202.5) | (134.5) | (182.5) | (114.5) | 14.16 | (10.5) |
| 2. 3:4 Peak, Mixed Fleet | ( 44.3) | ( 7.1) | 29.0 | ( 51.4) | ( 15.3) | 7.08 | ( 4.7) |
| 3. 2:3 | (136.0) | 55.7 | 110.4 | ( 80.3) | ( 25.6) | 9.44 | ( 5.6) |
| Express Bus Options: | | | | | | | |
| 1. 1:1 | 20.6 | ( 62.3) | ( 42.5) | ( 41.7) | ( 21.9) | 7.08 | ( 4.5) |
| 2. 2:3 | ( 9.8) | 37.8 | 62.3 | 28.0 | 52.5 | 4.72 | 8.5 |
| 3. 1:2 | (104.6) | 88.9 | 116.5 | ( 15.7) | 11.9 | 3.54 | ( .5) |
| Double-Header Options: | | | | | | | |
| 1. 1:2 | ( 1.1) | 29.6 | 38.8 | 28.5 | 37.7 | 1.18 | 28.1 |

NOTES:

1. Parentheses indicate a loss in revenue.
2. Parentheses indicate a cost increase.
3. Parentheses indicate a net operator loss.
4. Includes buses out of service due to maintenance requirements and the need for spares.
5. The median net annual operator gain is used.

TABLE 6.3

Summary of Operator Cost/User Benefit Tradeoff Analysis Results

| OPTION | (1) ANNUAL GAIN IN USER BENEFITS[1] ($x1000) | (2) ANNUAL COST SAVINGS[2] ($x1000) | | (3) = (1)+(2) NET ANNUAL GAIN [3] ($x1000) | | (4) BUSES PURCHASED[4] | (5) = (3)/(4) NET ANNUAL GAIN PER BUS PURCHASED[5] ($x1000) | |
|---|---|---|---|---|---|---|---|---|
| | | low | high | low | high | | low | high |
| Local Bus Options: | | | | | | | | |
| 1. 1:1 | 66.9 | (202.5) | (134.5) | (135.6) | ( 67.6) | 14.16 | ( 9.6) | ( 4.8) |
| 2. 3:4 Peak, Mixed Fleet | (147.7) | ( 7.1) | 29.0 | (154.8) | (118.7) | 7.08 | (21.9) | (16.8) |
| 3. 2:3 | (453.9) | 55.7 | 110.4 | (398.2) | (343.5) | 9.44 | (42.2) | (36.4) |
| Express Bus Options: | | | | | | | | |
| 1. 1:1 | 69.0 | ( 62.3) | ( 42.5) | 6.7 | 26.5 | 7.08 | .9 | 3.7 |
| 2. 2:3 | ( 43.5) | 37.8 | 62.3 | ( 5.7) | 18.8 | 4.72 | ( 1.2) | 4.0 |
| 3. 1:2 | (350.6) | 88.9 | 116.5 | (261.7) | (234.5) | 3.54 | (73.9) | (66.2) |
| Double-Header Options: | | | | | | | | |
| 1. 1:2 | ( 4.0) | 29.6 | 38.8 | 25.6 | 34.8 | 1.18 | 21.7 | 29.5 |

NOTES:

1. Parentheses indicate a loss of benefits.
2. Parentheses indicate a cost increase.
3. Parentheses indicate a net operator loss.
4. Includes buses out of service due to maintenance requirements and the need for spares.
5. The median net annual operator gain is used.

## TABLE 6.4

## Summary of Generalized Prices For Examined Scenarios

| SCENARIO | | Peak Period Peak Direction | Peak Period Reverse Direction | Offpeak |
|---|---|---|---|---|
| Local Bus | Base | $1.64 | $1.29 | $1.41 |
| | 1:1 | 1.59 | 1.29 | 1.40 |
| | 3:4 Peak | 1.70 | 1.37 | 1.44 |
| | 2:3 | 1.81 | 1.42 | 1.59 |
| Express Bus | Base | $3.28 | $2.68 | |
| | 1:1 | 3.09 | 2.68 | |
| | 2:3 | 3.37 | 2.86 | |
| | 1:2 | 4.29 | 3.05 | |
| Double Header | Base | $3.08 | | |
| | 1:2 | 3.16 | | |

# 7. CONCLUDING REMARKS AND RECOMMENDATIONS FOR FURTHER WORK

It is obviously impossible in a general study of this nature to draw conclusions on the desirability of articulated bus utilization on a particular route or in a specific local setting. Therefore, we would not presume to judge the merits of any local application. Nevertheless, the cautious stance that emerges from our work is apparently at some variance with the enthusiasm with which the articulated bus is viewed by at least a subset of transit operators. This different judgment is difficult to explain, but we might speculate that it is largely the result of our use of more extensive data and a more rigorous and comprehensive evaluation methodology than operators currently employ.

In any case, we share the view of transit operators that there may be significant changes over the next few years in the costs of articulated bus purchase and utilization. Undoubtedly, there will be improvements in the design and performance of articulated buses, and transit properties can be expected to benefit from the experience they gain with articulated bus operations. Changes in driver wage rates and the costs of fuel and maintenance can also be expected. There may, of course, also be significant changes in these costs for conventional bus alternatives. Clearly, the comparative costs of articulated bus service bear careful monitoring in the near term by those involved in making bus purchase decisions.

At the same time, there is a strong case for aggressive efforts to make the best use of the existing and growing number of articulated buses in U.S. transit vehicle fleets. Our review of experience to date suggests that operators have not yet taken the opportunity to making schedule and other operating changes needed to realize the potential benefits of articulated bus deployments. The need for special analytical and management efforts to realize the productivity enhancement potential of the articulated bus can be filled in a number of ways. First, there is a need for a planning methodology which can be used by operators to identify appropriate settings for articulated bus use and to optimize deployments for specific routes. The cost-benefit approach utilized in our study can, with further development and empirical validation, form the basis for a major part of this planning methodology. However, a more detailed level of analysis on a route-by-route basis will be required to investigate good deployment strategies. As mentioned previously, we believe simulation to be the most appropriate methodology for this purpose.

Second, several demonstration projects are recommended to experiment with alternative means of achieving productivity improvements with articulated buses. The projects would be conducted in cooperation with transit authorities who are already utilizing articulated buses. In these efforts, experiments would be conducted with route structures, schedules, and dispatching strategies to ascertain cost-effective efficiency-enhancing techniques for articulated bus utilization. The demonstrations would also provide a means of obtaining in-depth information on actual experiences with articulated buses which would not otherwise be available.

One project, which includes a precursor research activity, should focus on effective strategies for mixed use of articulated buses and conventional buses on the same route. This project would attempt to find and illustrate tactics to overcome some of the difficulties such as bus bunching which are thought to be exacerbated by mixed use of different size vehicles. Other demonstration projects could focus on specific topics other than service deployment such as fare collection, maintenance, and driver training. Some of the issues raised previously concerning these topics could be further explored and ameliorative measures could be tested. These projects would be carefully documented and evaluated and the results disseminated to the transit community.

A third recommended initiative is a follow-up study to update the data, analyses, and conclusions provided in this report. As mentioned previously, the operating experience and the cost of articulated bus utilization may change considerably over the next few years with potentially major implications for investment and deployment decisions. Surely, operators could benefit from more up-to-date information on relevant matters than we have been able to provide.

Perhaps, the greatest uncertainty in assessing the desirability of articulated bus utilization concerns the preferences of transit travellers which ultimately are major determinants of revenues and user benefits. These preferences must be taken into account for efficient service design for all vehicle types. Despite its importance, insufficient research has been done to reach conclusions on the value travellers place on attributes of service such as the availability of a seat, the components of travel time, the possibility of being passed-by by a full bus, etc., to identify the best uses of articulated buses. Consequently, we suggest that a major effort be mounted to estimate the consumer preference data needed for transit service design.

Our final recommendation is that UMTA consider the development and implementation of a modest program of technical assistance to operators to share information and understanding on articulated bus investment and deployment decisions and sound operating practices. If undertaken, this activity should be coordinated with the other activities that are recommended.

# APPENDIX A

## DWELL TIME MODELS DEVELOPED FROM THE DATA COLLECTED IN PITTSBURGH, SEATTLE, AND CHICAGO

Several alternative specifications for modelling dwell times were tried. The best dwell time models based on theoretical considerations, are presented in Table A.1 using the data from Pittsburgh, Seattle, and Chicago. (The Chicago models are included here for comparison, although known problems in the Chicago dwell time data ultimately prevented its use in this evaluation.) These are linear models of the form:

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

where:

$Y$ = estimated dwell time at a stop in minutes

$a$ = intercept term (door opening and closing time) in minutes

$x_1$ = number of boarders at a stop

$x_2$ = number of alighters at a stop

$x_3$ = number of passengers boarding or alighting through the rear door

$x_4$ = interaction term = 1 if there are both boarders and alighters at the same door at the same stop; 0 otherwise

$b_1$, $b_2$, $b_3$ and $b_4$ = coefficients (the units of each term of the model are minutes)

The resulting coefficients or parameter values of the models are shown in the table along with the standard error of estimate for each coefficient and the $R^2$ goodness of fit statistic. The coefficient is said to be statistically significant if its standard error is small in comparison to the coefficient value; when the standard error is higher than approximately one-half the coefficient value, the coefficient tends to be statistically insignificant. An $R^2$ of 1.00 is perfect; as $R^2$ values decrease, the statistical goodness of fit decreases. $R^2$ values below about 0.5 imply a weak relationship.

It is interesting to note the similarities in the dwell time models across the three cities. First, the intercept terms are remarkably consistent at around 0.11 minutes (6.6 seconds) for the articulated bus and around 0.07 minutes (4.2 seconds) for the conventional bus. The coefficents on boarding passengers and alighting passengers are quite similar for Pittsburgh and Seattle, with alightings consistently being somewhat faster than boardings, as is logical, and with the conventional bus consistently taking somewhat longer than the articulated bus to board or alight each passenger.

TABLE A.1

Dwell Time Model Parameters (and Standard Errors)

| | Variable | | | | | |
|---|---|---|---|---|---|---|
| | Intercept | Number of Boarders | Number of Alighters | Rear Ons + Rear Offs | Interaction Dummy Term | $R^2$ |
| Pittsburgh | | | | | | |
| Articulated Bus | .103 (.003) | .033 (.001) | .027 (.001) | -0.018 (.002) | ------* | .54 |
| Conventional Bus | .053 (.002) | .039 (.0007) | .029 (.0007) | -0.034 (.001) | .022 (.003) | .64 |
| (difference) | .05 | -.006 | -.002 | .016 | -.022 | |
| Seattle | | | | | | |
| Articulated Bus | .112 (.003) | .034 (.001) | .029 (.001) | -.018 (.001) | ------ | .59 |
| Conventional Bus | .072 (.003) | .038 (.001) | .031 (.001) | -.018 (.002) | .019 (.006) | .57 |
| (difference) | .04 | -.004 | -.002 | .000 | -.019 | |
| Chicago | | | | | | |
| Articulated Bus | .119 (.007) | .039 (.002) | .018 (.002) | -.002 (.004)** | ------ | .39 |
| Conventional Bus | .074 (.004) | .022 (.001) | .022 (.002) | -.018 (.003) | .044 (.007) | .42 |
| (difference) | .045 | .017 | .004 | .016 | -.044 | |

* Not statistically significant at .05 level in any of the articulated bus's dwell time models. Dropped from regression and re-estimated without it.

** Not statistically significant at .05 level. Value left in table to be consistent.

In Pittsburgh and Seattle, riders pay at the outer city end of the trip. Consequently, payment of fares is sometimes upon boarding, sometimes upon alighting, and fare payment times are averaged into both boarding and alightment times. In Chicago, riders pay upon boarding regardless of whether the trip is inbound or outbound, so one might expect a greater differential between boarding coefficients and alightment coefficients in Chicago; this proved to be the case for the articulated bus model (relative to Pittsburgh and Seattle), but the boarding coefficient for the conventional bus appeared to be excessively low. No separate "payment of fares" term proved to be statistically significant in any of the models.

The rear ons-and-offs coefficients are negative as expected (if some of the total boarders and/or total alighters at a stop use the rear door, it should reduce the dwell time otherwise resulting). Their value is consistently -0.018 except for Pittsburgh conventional buses and Chicago articulated buses, which seem too high (in absolute value) and too low respectively.

# APPENDIX B

## MODELING AND ESTIMATION PROCEDURES USED IN THE COST ANALYSIS

The cost analysis is based on a life cycle cost approach in which two alternative investments are considered and compared. The first is the base case in which there is an investment in an all-conventional bus fleet. The second case entails an investment in articulated buses which results in a mixed articulated and conventional bus fleet. In the base case, an existing all-conventional bus fleet is assumed to continue in operation for a specified number of years. Over that time span, these buses, as they reach the end of their useful lives, are replaced on a one-for-one basis with new conventional buses. In the articulated bus case, in which the fleet is initially the same as in the base case, the transit operator purchases A articulated buses in place of B conventional buses. It is assumed that the A articulated buses purchased replace the first B conventional buses that reach the end of their useful lives and that the resulting mixed articulated and conventional bus fleet is in operation for the same number of years as the all-conventional bus fleet in the base case. During this period, as the conventional and articulated buses reach the end of their useful lives, they are replaced on a one-for-one basis with new buses of the same type.

To estimate the costs of each alternative investment, the present value of its costs (PVC) is computed, where the present value is equal to the total of all present and future costs discounted by the opportunity cost of money. Theories of capital budgeting suggest that the present value approach is a most effective one to use when life cycle costs and alternative uses of money are being considered. This approach has been particularly emphasized for governmental decision-making and is endorsed by the Office of Management and Budget (OMB).[1] In calculating present value, a real, uninflated discount rate of 10% suggested by OMB in their economic feasibility evaluation guidelines, is used.[2] By assuming that all cost components used in the analysis will be subjected to the same inflation rate, all costs can be represented in 1980 constant dollars.

A 30 year time span is selected in order to capture accurately the life cycle capital costs that result from the deployment of articulated buses in many of the scenarios being examined in the study and compare those costs with the life cycle capital costs resulting from the deployment of conventional buses in the base case scenario. Initially, both conventional and articulated buses are assumed in the analysis to have 15 year lives when operated the same number of miles as an average bus in an all-conventional bus fleet. However,

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[1] Dooley, T., and J. Putukian, "Articulated Bus Investment Analysis," draft study, Transportation Systems Center, Cambridge, MA, January 1977.

[2] Office of Management and Budget Circular No. A-94 (Revised), Washington, DC. March 27, 1971.

the much lower yearly mileage that articulated buses would operate under many of the scenarios examined is assumed to lengthen articulated bus life substantially. The lengthened articulated bus life leads to the use of a 30 year time span rather than a 15 year one.

Base case and articulated bus case life cycle capital investments are modeled as follows. Let Y be the size of the initial all-conventional bus fleet.[3] The fleet at the beginning of Year 1 is assumed to have a uniform age distribution from 1 year to 15 years. In the base case, it is assumed that 1/15•Y buses will be replaced at the end of each year over the 30 year span.

In the modeling of the articulated bus replacement alternatives, it is assumed that some percentage of the conventional bus fleet will be replaced with articulated buses. Ten, 20 and 30 percent replacment rates are being considered. Four different articulated bus substitution rates are being examined:

- 1-for-1
- 3-for-4
- 2-for-3, and
- 1-for-2.

These replacement and substitution rates cover the range of those which a transit operator might consider. For each substitution rate, three different deployment scenarios are analyzed:

- peak period only deployment of articulated buses on express routes,
- peak period only deployment on local routes, and
- all day deployment on local routes (excluding very early morning, evening, and weekend services).

These scenarios and conbinations of these scenarios reflect a range of deployment options operators might consider.

Let S equal the particular articulated bus substitution rate being examined, i.e., 1-for-2, 2-for-3, etc., expressed as a decimal. It is assumed that beginning at the end of year 1, 1/15•Y of the conventional buses are replaced with 1/15•Y•S articulated buses, and in each subsequent year 1/15•Y of the conventional buses are replaced with up to 1/15•Y•S articulated buses until the desired percentage of the fleet (i.e., 10%, 20%, and 30% are being considered) is replaced with articulated buses. If it is assumed that articulated buses will operate the same number of miles as conventional buses,

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[3] In presenting the results on a normalized basis, i.e., net cost per articulated bus purchased, it will be seen that Y is divided out.

then once that replacement point is reached, 1/15•Y of the conventional buses would be replaced each year with 1/15•Y conventional buses through year 15. After that time articulated buses must be replaced again and the cycle, which began at year 1, would repeat. For example, the following replacement scenario would be assumed for 10% replacement with articulated buses:

year 1:[4] 1/15•Y conventional buses replaced with 1/15•Y•S articulated buses

year 2: 1/15•Y conventional buses replaced with 1/30•Y•S articulated buses and 1/30•Y conventional buses

year 3-15: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

year 16: 1/15•Y•S articulated buses replaced with 1/15•Y•S articulated buses

year 17: 1/30•Y•S articulated buses replaced with 1/30•Y•S articulated buses; 1/30•Y conventional buses replaced with 1/30•Y conventional buses

Year 18-30: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

However, this replacement scenario requires modification because articulated buses normally will be operated less than the average number of miles operated by conventional buses. Since efficient articulated bus utilization typically will occur at times of high passenger boarding (generally in the peak period only), and since conventional buses have a lower per mile operating cost than articulated buses, operating cost savings are gained by limiting articulated bus operation to periods of high passenger loading. The much lower yearly mileage that articulated buses consequently experience when deployed in this manner results in longer articulated bus life and shorter conventional bus life, since the average annual utilization of the remaining conventional buses in the fleet must rise. These modified bus lives must be taken into account in any articulated bus replacement scenario being modeled.

With each of the three deployment scenarios being examined, it is assumed that articulated buses will operate only the following percentage of the average mileage operated by buses in an all-conventional bus fleet:

peak period only deployment on express routes - 40%

peak period only deployment on local routes - 60%

---

[4] Denotes end of year.

all day deploymnet on local routes - 75%

All of these percentages assume that articulated buses will not be used in the evening and on weekends (except for special events, where they could prove to be useful). The peak period only express route percentage assumes that articulated buses operate in the four peak hours only. The peak period only local route percentage assumes that the relatively low peaking on local routes makes it possible for only 3/4 of the articulated buses to operate in the four peak hours only, with the other 1/4 being forced to operate all day, i.e., about 11 hours. The all day local route percentage assumes that articulated buses operate approximately 8 hours per day -- 50% in 5 peak hours and 50% all day (about 11 hours).

To illustrate the manner in which the reduced annual mileage of operation of articulated buses is dealt with in the analysis, consider the case where articulated buses are deployed in peak period local bus service and operate 60% of the average mileage operated by the conventional buses prior to articulated bus implementation. Assume prior to articulated bus implementation that each conventional bus is operated $M_0$ miles per year. Then the total mileage operated by the fleet is $M_0Y$ miles. If the articulated buses each operate $0.6M_0$ miles, and we assume that the conventional buses eliminated by articulated replacement also would have operated $0.6M_0$ miles, then, if X percent of the fleet is replaced by articulated buses, and $M_1$ represents the number of miles the remaining conventional buses will now be operated, it follows that:[5]

$$M_0Y = (0.6M_0)(XY) + M_1(1-X)Y$$

$$M_1 = (1-0.6X)M_0/(1-X)$$

For $X = 10\%$ $M_1 = 1.044M_0$
$X = 20\%$ $M_1 = 1.100M_0$
$X = 30\%$ $M_1 = 1.171M_0$

Bus lives are assumed to increase or decrease in direct proportion to the increase or decrease in usage. Under these circumstances, articulated buses would have a life of:

$$15/0.6 = 25 \text{ years.}$$

If 10% of the conventional bus fleet is replaced with articulated buses, conventional buses would have a life of:

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[5] Where some of the articulated buses replacing the conventional buses must operate in all day service and the conventional buses eliminated operated in the peak period only, then the articulated buses must be assumed to operate more miles than the conventional buses eliminated, and this difference must be accounted for in the calculation of $M_1$. This consideration is not reflected in the equation above.

15/1.044 = 14.4 years.

If it is assumed that buses are replaced only at the end of any year, then the replacement sequencing where 10% of the fleet is replaced with articulated buses is as follows:

year 1: 1/15•Y conventional buses replaced with 1/15•Y•S articulated buses

year 2: 1/15•Y conventional buses replaced with 1/30•Y•S articulated buses and 1/30•Y conventional buses

year 3-10: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

year 11: 2/15•Y conventional buses replaced with 2/15•Y conventional buses

year 12-14: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

year 15-16: no replacement

year 17-24: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

year 25: 1/10•Y conventional buses replaced with 1/10•Y conventional buses

year 26: 1/10•Y conventional buses replaced with 1/10•Y conventional buses and 1/15•Y articulated buses replaced with 1/15•Y•S articulated buses

year 27: 1/15•Y conventional buses replaced with 1/15•Y conventional buses and 1/30•Y•S articulated buses replaced 1/30•Y•S articulated buses

year 28: 1/15•Y conventional buses replaced with 1/15•Y conventional buses

year 29: 1/30•Y conventional buses replaced with 1/30•Y conventional buses

year 30: no replacement

The annual cost of any investment strategy is, for analysis purposes, divided into three components: capital costs, non-driver operating costs, and driver operating costs. Based on purchase prices for 1980 delivery, a 60-foot articulated bus with air conditioning has a capital cost in the range of

$235,000-$260.000.[6] The relative purchase prices of articulated and conventional buses will vary with order size and accessories desired, and many factors will determine the relative prices of the two buses in the future. Because of the possible range in the relative prices of the two buses and the sensitivity of the results to these relative prices, the articulated bus capital cost is represented in the analysis as a multiple, C, of the 1980 conventional bus capital cost, or $130,000C. In examining the results of the cost analysis, a range of values is used for this multiplier. The cost of special hoists needed to service the articulated buses is an added capital cost to be included in the articulated bus cases. It is assumed that 20 buses can use one hoist, which is estimated to cost $30,000 and have a life of 20 years. Conventional and articulated bus salvage values are assumed to be 3% of original capital costs. Because existing operational experience at U.S. properties gives little indication of the circumstances under which additional garaging facilities will be needed for articulated buses and how these facilities will impact the need for replacement of existing conventional bus garaging facilities, fixed facility capital costs are assumed to be identical for all investment strategies. In reality, these costs may be higher for the articulated bus strategies.

Non-driver operating costs (i.e., vehicle maintenance, fuel, and insurance) can be compared in terms of average annual costs given the same number of miles of operation for both bus types. Overhead costs are assumed to be the same for all investment strategies. APTA 1980 operating statistics for a sample of U.S. transit properties having more than 400 buses in their fleets indicate the following average annual non-driver operating costs per conventional bus:[7]

| | | |
|---|---|---|
| maintenance (including labor) | = | $14,000 |
| fuel | = | 10,000 |
| insurance | = | 4,000 |
| Total | = | $28,000 |

Since most transit properties are self-insured, insurance costs are based upon liability claim costs.

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[6] Capital costs are based on bid price data obtained from MAN and from UMTA's Office of Transit Assistance. Articulated bus capital costs in 1980 are obtained by extrapolation between capital costs for buses delivered in late 1978 and ones scheduled for delivery in 1982.

[7] (1) American Public Transit Association, "Transit Labor Expense Components for Transit Systems with Fiscal Years Ending in January, February, March, April, May and June 1980," Washington, DC, February 2, 1981.
(2) American Public Transit Association, "Comparative Labor Practices; Report No. 2: Number of Vehicles by Type (as of October 1, 1980)," Washington, DC, January 2, 1981.
(3) Data on fuel usage and costs at selected transit properties supplied in telephone conversations with American Public Transit Association during April 1981.

Operating cost data for the 60-foot articulated bus are derived by comparative analysis with conventional buses. The range of articulated bus maintenance costs is taken to be 1.5 to 2 times the maintenance costs of conventional buses based on the findings of Chpater 4. Fuel costs for articulated buses are estimated to be 10% higher fuel than for conventional buses on the basis of an average 10% higher fuel consumption indicated in data from five cities (see Table 5.1). However, the rather small differences in fuel consumption between the two bus types should be viewed with caution since articulated buses at the five sites tend to be operated on more fuel efficient routes (i.e., more express routes) than the average routes traversed by the conventional bus fleet. Note that in Chicago, where articulated buses are operated on diverse routes, the fuel consumption figures are 15% higher for articulated buses. Insurance costs reflect the higher accident rate for articulated buses, which is twice that of conventional coaches as reported in Chapter 4.

Thus, an articulated bus, if operated the same number of miles as an average conventional bus, is estimated to have the following non-driver operating costs per vehicle:

maintenance (including labor) = $21,000 to 28,000
fuel = 11,000
insurance = 8,000
Total = $40,000 to 47,000

Since it is assumed that articulated buses will operate fewer miles than the average operated by the original all-conventional bus fleet, and as a result the remaining conventional buses will operate additional miles, then adjustments must be made to both the articulated and conventional bus operating costs. Since these operating costs are mileage based, they would be adjusted in the same fashion as the bus lives are adjusted, i.e., in direct proportion to the decrease or increase in usage. Again using the example of articulated bus deployment on peak period local service and 10% articulated bus replacement (with articulated buses operating 40% fewer miles and conventional buses operating 4.4% more miles than the original fleet average), operating costs/articulated bus would be reduced 40% and operating costs/conventional bus would be increased 4.4%.

Driver labor costs, unlike capital costs and non-driver operating costs, are not calculated separately for the articulated bus investment scenarios and for the base case all-conventional bus scenario. Rather, annual driver operating cost savings attributable to a particular articulated bus investment strategy are calculated directly. These cost savings accrue directly from the elimination of in-service conventional buses resulting from the substitution of articulated buses in some fractional ratio. APTA statistics on average hourly driver wage rates and on costs for fringe benefits and premium pay are used to calculate the driver operating cost savings resulting from the elimination of each in-service bus.[8]

The elimination of each in-service conventional bus operating in the peak period only is assumed to save annually the driver labor costs associated with working one split shift assignment (composed of a morning and afternoon piece of work) on each of the approximately 250 weekdays in a year. Low and high estimates of cost savings are calculated based on low end and high end estimates of hourly driver wage rates of \$9 and \$11, respectively. Using the \$9 hourly wage rate, the labor cost savings per in-service bus eliminated, $\Delta C_1$, is calculated as follows:

$$\Delta C_1 = 8 \text{ hrs./day} \times 250 \text{ weekdays/yr} \times \$9.00\text{/hr. base wage} \times 1.30 \text{ pay factor} \times 1.35 \text{ fringes}$$

$$= \$31{,}600\text{/in-service bus eliminated.}$$

Using the \$11,00 per hour base wage rate,

$$\Delta C_2 = \$38{,}600.$$

The base wage range of \$9-\$11 per hour and the 1.35 factor for fringe benefits are determined by selecting a sample of transit properties with over 400 buses, obtaining their base wage rate and fringe benefits factors from APTA statistics, and selecting the sample means. The 1.30 factor, also derived from APTA statistics, takes into account the following: premium pay for pieces of work that are spread out in time, 8 hours pay for a small incidence of tripper assignments,[9] nonoperating paid work time, and additional base and overtime pay for those work assignments which exceed 8 hours.

The elimination of each in-service conventional bus operating during the entire day (weekdays only) is assumed to save annually the driver labor costs associated with working one straight 8 hour driver assignment and one half of a split shift assignment on each weekday in a year. The labor cost savings per in-service bus eliminated, $\Delta C_2$, can be calculated in terms of $\Delta C_1$, calculated above, and $\Delta C_S$, the cost savings from eliminating a straight 8 hour driver assignment:

$$\Delta C_2 = \Delta C_S + {}^1/_2 \Delta C_1$$

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[8] (1) American Public Transit Association, "Top Hourly Wage Rate Summary -- Part I," Washington, DC, rates reported through March 23, 1981.
(2) "Transit Labor Expense Components," op cit.

[9] Tripper assignments are assignments of single pieces of work in either the morning or afternoon peaks which cannot be joined to form split shifts (because of work rule constraints).

Low and high end estimates of cost savings are calculated based on the \$9 and \$11 estimates of driver wage rates. Using the \$9 hourly wage rate, $\Delta C_2$, is calculated as follows:

$$\Delta C_S = 8 \text{ hrs/day} \times 250 \text{ weekdays/yr.} \times \$9.00\text{/hr. base} \times 1.10 \text{ pay factor} \times 1.35 \text{ fringes} = \$26{,}730$$

$$\Delta C_2 = \$26{,}730 + {}^1/_2(31{,}600) = \$42{,}600 \text{ in-service bus eliminated}$$

Using the \$11.00 per hour base wage rate,

$$\Delta C_2 = \$52{,}000$$

Note that the factors used in the calculation of $\Delta C_S$ are the same as those used for $\Delta C_1$ except for the pay factor, which is much lower because the premium costs of split shifts are not incurred.

Total driver labor cost savings resulting from the implementation of any articulated bus replacement strategy are calculated by determining the number of in-service conventional buses that are eliminated and multiplying that number by the annual driver labor cost savings per in-service bus eliminated. The articulated bus substitution rate is, of course, the major determinant of the number of in-service buses that are eliminated. The fewer the number of in-service articulated buses substituted for a given number of in-service conventional buses the greater the number of in-service conventional buses eliminated. However, in determining the number of in-service conventional buses that are eliminated, other factors must also be taken into account.

The first is that buses are out of service some percent of the time either for scheduled or non-scheduled maintenance. Twelve percent of the conventional buses in a conventional bus fleet are assumed to be out of service at any one time. The 12% figure is assumed to be made up of the following three components:

4% of vehicles in scheduled maintenance
4% of vehicles in non-scheduled maintenance
4% of vehicles for spares to cover in-service vehicle breakdowns and times when non-scheduled maintenance is higher than average

Using the 12% out of service figure, the elimination of a conventional bus actually yields a reduction of only 0.88 in-service buses.

Another factor is that in-service travel times are longer with articulated buses. One-way in-service travel times on articulated buses are estimated to be as much as 7 minutes (about 10%) greater than on conventional buses depending on the passenger load levels and boarding-deboarding patterns. The travel time differential is greatest on local service and least on express service. The higher in-vehicle travel times translate into a need to utilize more vehicles to provide a comparable frequency of service since vehicles cannot be turned around as quickly to make subsequent trips. This reduces the number of in-service conventional buses that can be eliminated with articulated bus implementation and hence cuts into the potential labor savings. The need for more vehicles also results in higher capital expenditures. The impact of longer travel times on vehicle fleet requirements is calculated as follows.

The fleet size N (not including spares for downtime) is dependent upon n, the number of bus trips on a route during a peak period of duration PPL (in minutes), and T, the total round-trip time (in minutes) for a bus trip including any layover. When the round trip time, T, is equal to or greater than the peak period duration, PPL, then the fleet size N will be equal to n. When T is less than PPL, some or all of the buses can make more than one bus run during the peak period, thus reducing the fleet requirements. For instance, if T is 60 and PPL is 120, then all buses can make two bus runs during the peak period and N would be equal to n/2 but rounded upward to the nearest integer. Whenever the ratio of PPL to T is an even integer, then N would be equal to n/(PPL/T) but rounded upward to the nearest integer. However, whenever PPL/T is not an even integer, then some buses would be able to make more bus runs than others. Suppose, for instance, that the PPL/T ratio was 1.5; then some of the fleet would make two runs during the peak period while others would make only one run. As an approximation:

$$N = [n/(PPL/T)]$$

where = [---] indicates rounding off to the next highest integer.

In practice, this fleet size estimating procedure needs to be applied on each route. Occassionally, buses are run on more than one route. In that case, more complex fleet size estimating procedures should be used.

The effect that an I% increase in in-service travel time will have on N is influenced by the tightness of the existing schedule, i.e., whether existing layovers are at or above the minimum allowed, the complexity of the route structure, and the degree of peaking on the route. Where the existing schedule is tight, n/(PPL/T) will be at or just below an integer value. An I% increase in in-service travel time will likely increase N by more than I%, because while n/(PPL/T) will increase by approximately I% (actually slightly less because layover times probably wouldn't increase) [n/(PPL/T)] will likely increase by more. Similarly, where the existing schedule is loose, an I% increase in in-service travel time will likely increase N by less than I%. Were every route to have one origin and one destination and even headways throughout the day, there would be a tendency for schedules to be on the tight side since the desired efficiencies achieved from doing so would often be attainable, and an I% increase in in-service travel time would on average require a somewhat more than I% increase in N. However, the multiple origins and/or destinations of many routes plus non-uniform frequencies during the peak which result in many buses making only one trip each peak period tend to produce many schedules which are much looser, i.e., many of the actual layover times far exceed the minimum required and round-trip running times are less critical for buses making only one peak period trip. Where this occurs, an I% increase in in-service travel time will likely produce a less than I% increase in N. The greater the complexity of the route and the higher the degree of peaking, the lesser is the impact on N of an I% increase in in-service travel time.

The impact on N of the increased in-vehicle travel times with articulated buses is estimated under each of the three replacement scenarios for the following two passenger loading levels:

- 150% of those on conventional buses (to cover 3-for-4, 2-for-3, and 1-for-2 replacement), and
- same as on conventional buses (to cover 1-for-1 replacement).[10]

Thus a total of six operating conditions are being examined. Only two loading levels are considered because of the judgmental nature of the estimates. The impact on all day local service must be analyzed by examining separately the impact on peak period service only and the impact on mid-day service only and then combining the two impacts.

The impact on N of the increased in-vehicle travel times with articulated buses is estimated under each of the six settings (i.e., two loading levels for each of three scenarios) using the following procedure. Roundtrip travel time components under conventional bus operation are specified on a percent basis to show the relative contribution of each component. Values for peak and reverse direction travel times under articulated bus operation are calculated in terms of percentage increases (shown in parenthesis) using Table B.1 and estimates of relative passenger activity and number of stops. It is assumed that in peak period service layover times cannot be adjusted downward to compensate for higher in-vehicle travel times but that the layover times can be reduced by 10% in the off-peak to so compensate. Using the percentage increase in T obtained by summing the estimated changes in each travel time component (i.e., peak direction service, reverse direction service, layover time), a guesstimate is made of the impact of that increase on N. The higher the degree of peaking, the greater the estimated reduction (to account for the fact that higher in-vehicle travel times have no effect on vehicle requirements where buses are making only one peak direction trip in a peak period).

Referring to Table B.1, the values of percent increase in N derived from this estimating procedure and used in our analysis are as follows:

| | |
|---|---|
| peak period express service (150% pax loads): | 1.5% |
| peak period express service (100% pax loads): | 0% |
| peak period local service (150% pax loads): | 4.5% |
| peak period local service (100% pax loads): | 1.5% |
| all day local service (150% pax loads): | 4.5% |

---

[10] Actual changes in passenger load are clouded by changes in demand that will occur because passenger level of service is modified (see Section 6).

## TABLE B.1

## Impact of Longer Articulated Bus Travel Times on Vehicle Fleet Requirements

### Peak period only express service (pax loads 150% those of conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 51% | 39% | 10% | 100% | - |
| with articulated buses | 53.0%(+4%) | 39.4%(+1%) | 10% | 102.4% | 2.4% |

2.4% increase in T ⟶ 1.5% increase in N

### Peak period local service (pax loads 150% those of conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 51% | 39% | 10% | 100% | - |
| with articulated buses | 55.6%(+9%) | 39.8%(+2%) | 10% | 105.4% | 5.4% |

5.4% increase in T ⟶ 4.5% increase in N

### Mid-day local service (pax loads 150% those of conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 46% | 42% | 12% | 100% | - |
| with articulated buses | 49.7%(+8%) | 44.5%(+6%) | 10.8% | 105% | 5% |

5% increase in T ⟶ 4.5% increase in N (during mid-day only)

Notes: T = round trip travel time
N = fleet size
Travel time components represented in terms of the percent of conventional bus round trip running time.
Figures in parenthesis represent the percent increase in the travel time component with articulated buses.

TABLE B.1 (cont'd)

Impact of Longer Articulated Bus Travel Times on Vehicle Fleet Requirements

Peak period express service (pax loads same as for conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 51% | 39% | 10% | 100% | - |
| with articulated buses | 51.5%(+1%) | 39% | 10% | 100.5% | 0.5% |

Assume this 0.5% increase in T can be absorbed in the schedule.

Peak period local service (pax loads same as for conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 51% | 39% | 10% | 100% | - |
| with articulated buses | 52.5%(+3%) | 39.4%(+1%) | 10% | 101.9% | 1.9% |

1.9% increase in T ⟶ 1.5% increase in N

Mid-day local service (pax loads same as for conventional buses)

| | peak direction travel time | reverse direction travel time | layover time | total travel time (T) | % increase in T |
|---|---|---|---|---|---|
| with conventional buses | 46% | 42% | 12% | 100% | - |
| with articulated buses | 46.9%(+2%) | 42.8%(+2%) | 10.8% | 100.5% | 0.5% |

Assume this 0.5% increase in T can be absorbed in the schedule.

Notes: T = round trip travel time
N = fleet size
Travel time components represented in terms of the percent of conventional bus round trip running time.
Figures in parenthesis represent the percent increase in the travel time component with articulated buses.

all day local service (100% pax loads): 1.0%[11]

These estimates of increase in N are used in the analysis to adjust upward the number of articulated buses that must be purchased and adjust downward the labor savings that can be realized with articulated bus replacement. Non-driver operating costs are assumed to be unaffected because the total number of vehicle miles operated is unaffected. With more buses each operating fewer miles, articulated bus life must be adjusted upward slightly.

One other factor to be considered in assessing the costs of articulated bus utilization is a higher incidence of road calls and maintenance with articulated buses. Without a greater number of articulated buses available, passengers on routes on which these buses are running would encounter more missed trips than they would on routes running conventional buses. It is estimated that 4% more articulated than conventional buses are needed to insure that the articulated bus' higher incidence of road calls and repairs does not lead to a higher incidence of missed trips.

The 4% figure is derived as follows. Twelve percent of the conventional buses in a conventional bus fleet have been assumed to be out of service at any one time, with the 12% figure made up of the following three components:

4% of vehicles in scheduled maintenance

4% of vehicles in non-scheduled maintenance

4% of vehicles for spares to cover in-service vehicle breakdowns and times when non-scheduled maintenance is higher than average .

Articulated bus maintenance and road call data collected in Chicago and Phoenix suggest that the incidence of in-service vehicle breakdowns and non-scheduled maintenance with articulated buses is at least 50% higher than it is for conventional buses. Thus, it is assumed that 12% of the articulated buses in a fleet will be out of service at any one time due to scheduled and non-scheduled maintenance versus 8% for conventional buses, a difference of 4%. The 4% figure is used in the analysis to adjust upward the number of articulated buses that must be purchased. Total operating costs are assumed to be unaffected by this 4% increase in fleet size because the total number of vehicle hours and miles operated is unaffected. With more buses each operating fewer miles, articulated bus life must be adjusted upward slightly.

All of the cost factors that need to be considered have now been dealt with. To understand how each of these factors is integrated into the analysis, some sample annual cost calculations are presented and explained.

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[11] Derived from averaging peak and off-peak percent increases (weighted toward the peak period percent increase).

## Sample Annual Cost Calculations

Base case: 1/15 of conventional buses replaced one-for-one with conventional buses throughout the 30 year time stream

### Annual cost (any year)

$$\text{Capital cost} = (130{,}000 - 3{,}900)(0.0667Y)$$

$$\text{Non-labor operating cost} = 28{,}000Y$$

130,000 - conventional bus capital cost

3,900 - conventional bus salvage value

0.0667Y - number of conventional buses replaced, i.e., 1/15 of total fleet Y

28,000 - conventional bus annual non-labor operating cost

Articulated bus replacement: 1/15 of conventional buses replaced with articulated buses each year until 20% of the fleet is equipped with articulated buses, and then as conventional and articulated buses reach the end of their useful lives they are replaced on a one-for-one basis with new conventional and articulated buses respectively; articulated buses are substituted 2-for-3 in peak period only express service.

### Annual cost (end of year 3)

$$\text{Capital cost} = (130{,}000C + 1{,}500)(2/3)(0.0667Y)(1.015)(1.04) - 3{,}900(0.0667Y)$$

$$\text{Non-labor operating costs} = (0.4)(40{,}000)(2/3)(0.2Y) + (1.15)(28{,}000)(0.8Y)$$

$$\text{Labor savings} = (31{,}600)(0.88)[0.2Y - (2/3)(0.2Y)(1.015)]$$

130,000C - articulated bus capital cost

1,500 - hoist capital cost/articulated bus

3,900 - conventional bus salvage value

(2/3)(0.0667Y) - number of articulated buses purchased based on 2-for-3 articulated bus substitution rate, i.e., 1/15 of conventional bus fleet, Y, replaced by (2/3)(1/15 Y) articulated buses, before correction for other factors

(2/3)(0.0667Y)(1.015)(1.04) - number of articulated buses purchased corrected for additional buses needed because of slower articulated bus travel times and greater incidence of being out of service

$\frac{(0.4)(40,000)}{(1.015)(1.04)}$ - non-labor operating cost/articulated bus (using low end maintenance costs) corrected for 40% mileage use and for the additional buses needed for the reasons mentioned above

(2/3)(0.2Y)(1.015)(1.04) - total number of articulated buses in operation (note that the 1.015 and 1.04 factors cancel out when total non-labor operating cost is calculated)

(1.15)(28,000) - non-labor operating cost/conventional bus corrected for 115% mileage use

0.8Y - total number of conventional buses in operation

0.2Y - total number of conventional buses replaced

(2/3)(0.2Y)(1.015) - total number of articulated buses substituted for the conventional buses; note that the 1.04 out of service correction factor is not included because the extra number of articulated buses needed to compensate for the greater out of service incidence has no impact on the number of trips with conventional buses that are eliminated

0.2Y - (2/3)(0.2Y)(1.015) - total number of conventional buses eliminated

[0.2Y- (2/3)(0.2Y)(1.015)](0.88) - total number of in-service conventional buses eliminated

31,600 - labor savings/in-service conventional bus eliminated

Annual cost (end of year 4)

Capital cost - same as in base case

Non-labor operating costs - same as in articulated bus replacement for end of year 3

Labor savings - same as in articulated bus replacement for end of year 3

For a given bus investment strategy, annual costs for each of the 30 years in the analysis time stream are calculated using cost components developed as in the sample calculations above. The present value of costs (PVC) for the investment strategy is calculated by finding the present value of each of the 30 years of annual costs at the 10% discount rate and summing all of the present values.

# APPENDIX C

## CONSUMER SURPLUS CONCEPT

The "consumer surplus" concept provides a simple mechanism for translating service impacts into a dollar measure. In essence, consumer surplus is the difference between the price that a person would be willing to pay for a good or service and the price charged, summed over all persons purchasing that good or service. Graphically, it is the area bounded by the demand curve, the equilibrium price line and the zero volume line (see Figure C.1).

To employ this concept in the analysis of service impacts, the "price" must be the total price (also called the "generalized price") of all service components and the demand curve must describe the ridership response to changes in the generalized price. Assuming for a moment that such a generalized price is calculable for bus services, the change in consumer surplus resulting from a change in the service (e.g., a substitution of articulated buses for conventional buses) can be viewed as the difference in consumer surplus areas (see Figure C.2). The magnitude of this change can be closely approximated as:

$$\Delta CS = (P-P')*(V+V')/2$$

where

$\Delta CS$ is the change in consumer surplus (dollars)
$P$ is the original generalized price
$V$ is the original volume
$P'$ is the new generalized price
$V'$ is the new volume.

Using this formula, a dollar measure of the service impacts (i.e., the change in consumer surplus) can be computed and can be directly compared against the cost of implementing the service change. The comparison is a direct one if all costs and benefits of the change are included in these measures: the change is cost-effective if the change in user benefits (i.e., the change in consumer surplus) exceeds the change in costs.

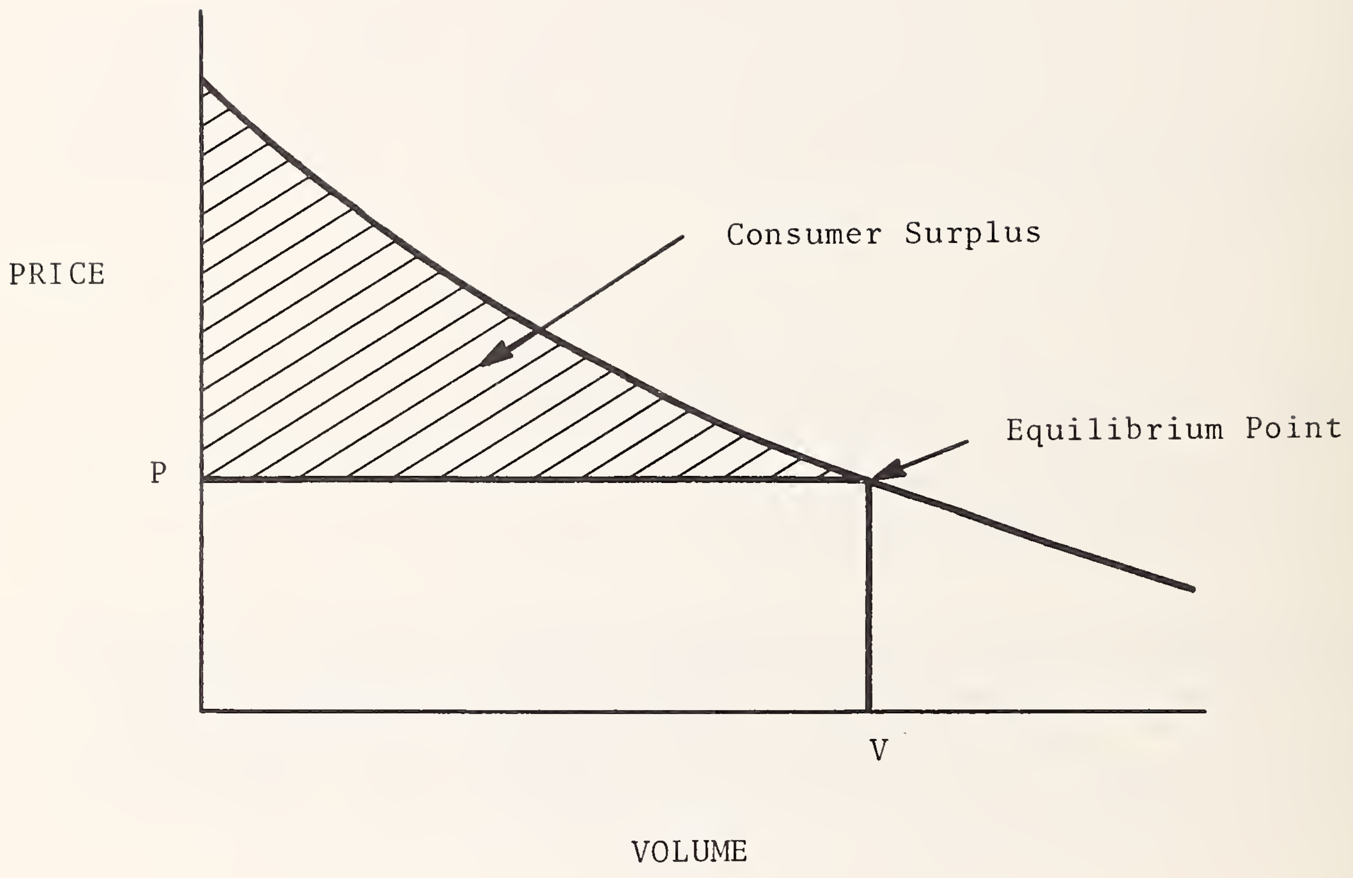

FIGURE C.1

The Consumer Surplus Concept

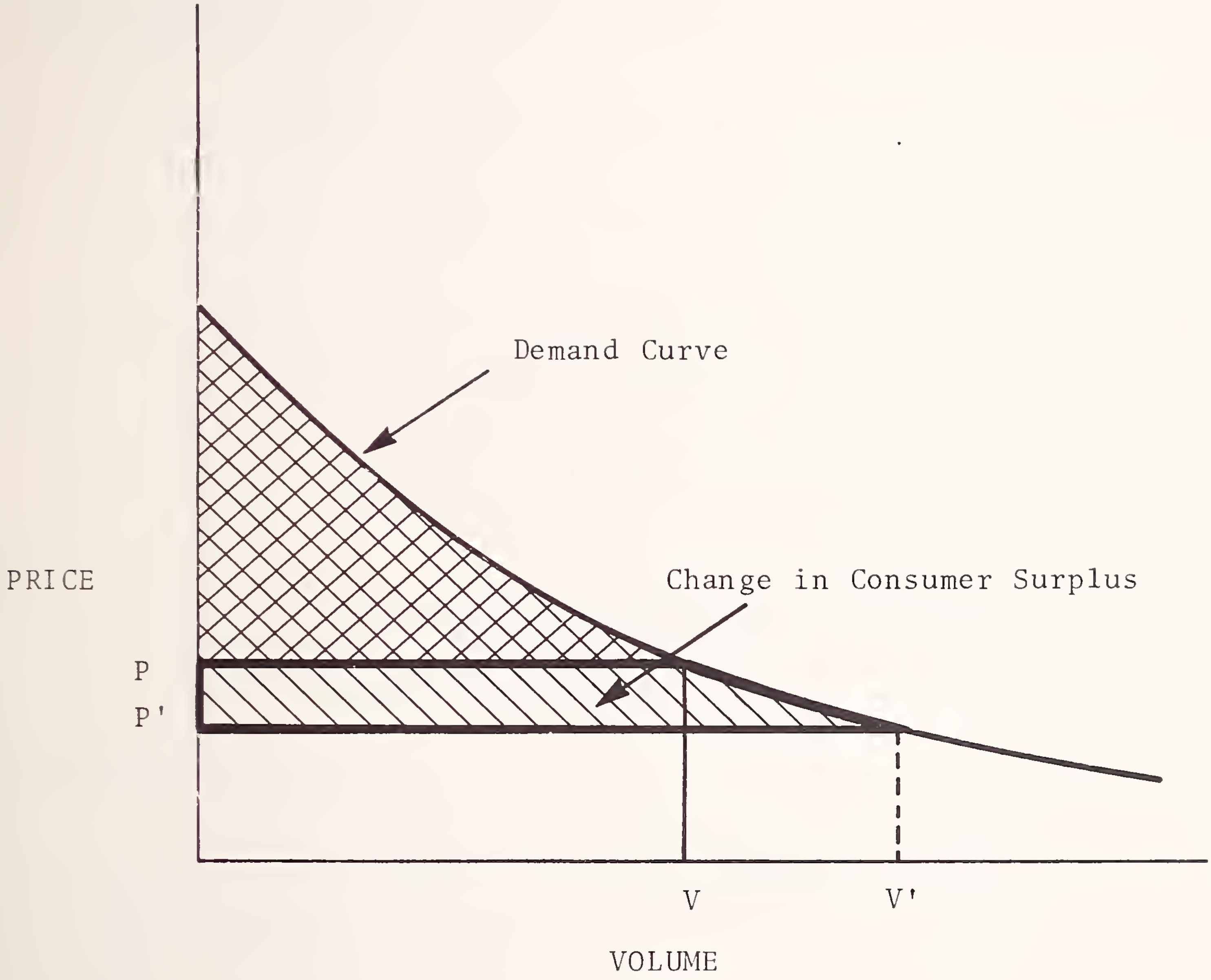

FIGURE C.2

Change In Consumer Surplus

# APPENDIX D

## A SIMPLE DEMAND MODEL FOR TRADEOFF ANALYSIS

The tradeoff analysis scenarios in Section 6 rely on a mathematical model of demand to project the ridership impacts of a change in service. This demand model was developed by first identifying a number of behavioral properties of demand that were judged to be applicable in most cases involving articulated buses, then contriving a mathematical formula that embodied those behavioral properties.

It was decided that the model must possess the following structural characteristics:

1. All measures of service must be reducible to a common measure. This permits rates of substitution to be computed for any two measures of service (e.g., the fare equivalent of a minute of travel time).

2. The reduced measures of service must be additive. This permits the computation of a single composite measure of service.

3. The ratio of the volume of ridership expected after a service change to the volume existing before the change must be expressable as a function of the difference in composite measures of service. Furthermore, this function must be smooth, must result in a steadily declining ratio as the relative service quality decreases, must result in non-negative ridership ratios over the entire range of service differences and must produce a ratio of 1 when the composite service measures are identical.

4. Five measures of service must be included: the expected in-vehicle travel time, the expected wait time, the average probability of getting a seat,[1] the average probability of getting bypassed by at least one bus, and the average fare.

Furthermore, it was decided that the demand model must exhibit the following behavioral traits:

1. The fare elasticity must be approximately -.3 to adhere to the well-established Simpson-Curtin Rule.[2] In practice, this means that for a 1% increase in fare, the model must produce a .3% decrease in ridership.

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[1] This factor represents the likelihood of getting a seat at the time of boarding only and does <u>not</u> cover the possibility of getting a seat later in the trip.

[2] Curtin, John F., "Effect of Fares on Transit Riding," Highway Research Record 213, Highway Research Board, Washington, DC, 1968, p. 13

2. The value of in-vehicle time must be \$3.00 per hour, meaning that a travel time savings of one minute is equivalent to a fare reduction of 5¢. This value is lower than the values used in most bus demand models and will tend to favor articulated buses (which have longer travel times in general).

3. The value of wait time must be 1.5 times the value of in-vehicle time. Again, this is somewhat lower than values typically used and results in a possible bias in favor of the articulated buses which generally have longer headways.

4. The importance of getting a seat should increase as the expected in-vehicle time increases and should be scaled so that the difference in value for being certain of sitting instead of being certain of standing for a 20 minute ride is equivalent to a 20¢ fare reduction.

5. The importance of getting bypassed should increase as the expected wait time increases and should be scaled so that a 1% absolute decrease in the chance of being bypassed on a route with a headway of 10 minutes is equivalent to a 5¢ fare reduction.

Based upon these structural and behavioral requirements, a demand model was developed which has the following form:

$$V_a = V_b * e^{k(D_a - D_b)}$$

where

$V_b$ and $V_a$ are the before and after ridership volumes, respectively;
$D_b$ and $D_a$ are the before and after composite service measures, respectively; and
$k$ is a parameter that is set to ensure adherence to the Simpson-Curtin Rule.

The composite service measure, D, is computed as

$$D = IVTT*(.05-.01*PS) + OVTT*(.075+PB) + FARE$$

where D is the composite measure of service (in dollars);
IVTT is the expected in-vehicle travel time (in minutes);
OVTT is the expected wait time (in minutes) to the first bus, (in minutes);[3]
FARE is the average fare (in dollars);
PS is the average probability of sitting; and
PB is the average probability of getting bypassed.

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[3] OVTT does <u>not</u> include any wait time due to being bypassed. The PB term must convey both the pure impact of being bypassed and the impact of the extended wait.

Notice that an increase in D represents a decrease in the level of service; consequently, parameter k must be negative. In all of the local bus scenarios (A1-A3), k was set to -.6 while a value of -.2 was used in the express bus scenarios (B1-B3 and C1).

# APPENDIX E

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# APPENDIX F

## REPORT OF NEW TECHNOLOGY

A thorough review of the work performed under this contract has revealed no significant innovations, discoveries, or inventions at this time. In addition, all methodologies employed are available in the open literature. However, the findings in this document do represent new information and should prove useful throughout the United States in designing and evaluating future transportation demonstrations.

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